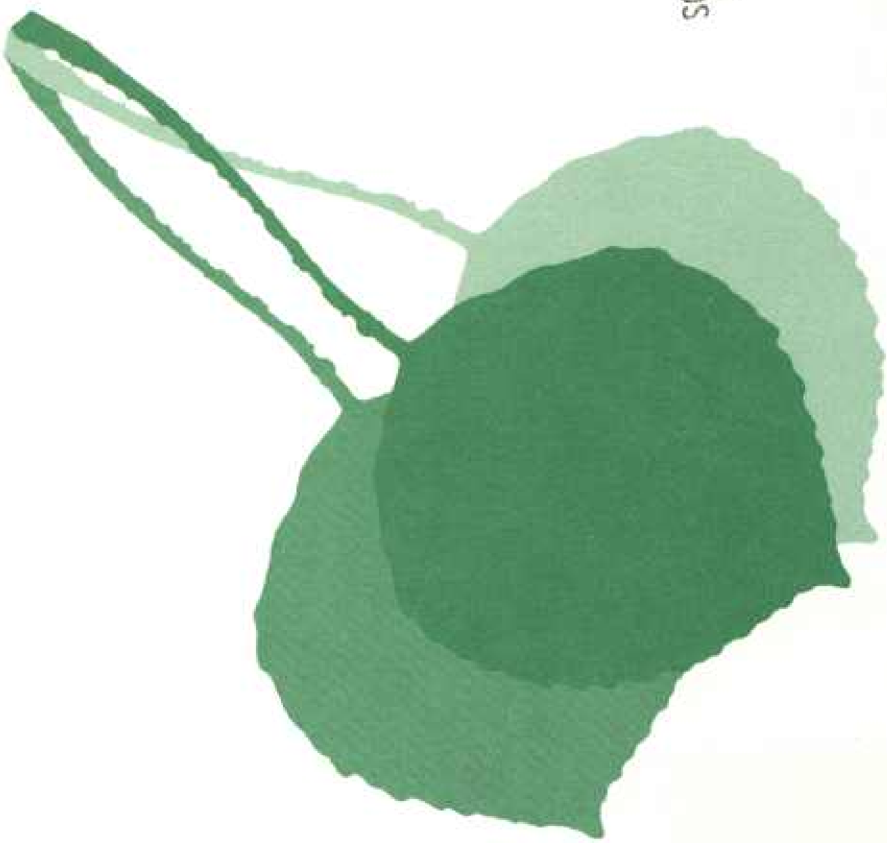
Quaking Aspen:

Silvics & Management in the Lake States

U.S. Department of Agriculture
Forest Service
Agriculture Handbook No. 486



QUAKING ASPEN: SILVICS AND MANAGEMENT IN THE LAKE STATES

by

Kenneth A. Brinkman, Principal Silviculturist (Retired), and
Eugene I. Roe, Research Forester (Retired),
North Central Forest Experiment Station

Agriculture Handbook No. 486

December 1975

Forest Service
United States Department of Agriculture

Library of Congress Catalog Card No. 75–600053

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402—Price $1.45
Stock Number 001–000–03462–6
Class Number A 1.76:486

25% discount allowed on orders of 100 or more to one address

Brinkman, Kenneth A., and Roe, Eugene I.
1975. Quaking aspen: silvics and management in the Lake States. U.S. Dep. Agric., Agric. Handb. 486, 52 p., illus.

Summarizes results of 45 years of research in aspen silvics and management in the Lake States. Discusses regeneration, growth and yield on various sites, effects of thinning, the present and potential markets, and the wildlife and recreation values of aspen. Provides guidelines to timberland managers for growing continuous crops of aspen on various sites.

OXFORD: 223:181:176.1.
KEY WORDS: Site requirements, regeneration, protection, growth rates, yield, thinnings, wildlife habitat, *Populus tremuloides; P. grandidentata.*

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S. Department of Agriculture, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

PREFACE

National timber and wood fiber needs are steadily increasing. At the same time, greater demands are being made on forest lands for other purposes. Forest managers thus are faced with a complex problem: how to increase wood production without causing unacceptable adverse effects on scenic, watershed, and recreation values. Increasing interest is being shown on the possibility of more intensive management of aspen as one solution to this urgent problem.

In many respects, aspen meets the specifications for the ideal forest tree. Its vigorous suckers make it easy to regenerate with minimum site disturbance. It grows rapidly and is so intolerant that natural thinning and pruning occur. Stands mature in relatively few years. Industry can use aspen wood for pulp, paper, and fiberboard; larger trees can be used for lumber or veneer. At all stages in their development, aspen stands furnish food and cover for wildlife. And the golden aspen leaves provide spectacular fall landscapes.

The silvics and management of aspen have been studied for some 45 years in the Lake States and Canada. Results of this research and the knowledge and experience of forest managers were combined to provide this summary of what is now known about growing the aspen forest for wood and other products.

Some of this information was presented at the Aspen Symposium (August 28-31, 1972, Duluth, Minnesota). Although hundreds of other publications were reviewed, we included only the most recent or more pertinent papers in the list of literature cited. This report also contains previously unpublished research results; a special effort was made to include the latest data on how much thinnings can increase volume and value yields.

Aspen site requirements, regeneration, protection, growth rates, and yield are discussed. No attempt was made to prescribe treatments and practices to maximize volume and value yields for all possible combinations of site quality, stand condition, and anticipated markets. Instead, general aspen management guidelines are presented. With suitable modifications to fit local situations, these guidelines can be followed to improve management of the aspen resource in the Lake States.

ACKNOWLEDGMENT

The authors gratefully acknowledge the invaluable assistance of many colleagues in the North Central Forest Experiment Station and Region 9 of the USDA Forest Service in the preparation of this publication. We are also indebted to the following individuals for constructive review of the manuscript: Dr. J. S. Maini and Dr. G. A. Steneker, Canadian Forestry Service; Dr. Frank D. Irving and Z. A. Zasada, University of Minnesota; R. Schantz-Hansen, Northwest Paper Company, Cloquet, Minnesota; R. W. Schneider, M. J. Salisbury Company, Grand Rapids, Minnesota; and Paul O. Rudolf, St. Paul, Minnesota.

CONTENTS

QUAKING ASPEN:

SILVICS AND MANAGEMENT IN THE LAKE STATES

by Kenneth A. Brinkman and Eugene I. Roe[1]

INTRODUCTION

The original upland forests of the Lake States are commonly pictured as extensive pure stands of pine[2] (eastern white pine and red pine), northern hardwoods, white pine and hardwoods, or farther to the north, of white pine mixed with white spruce and balsam fir. However, records indicate that there were large areas in Minnesota at least that could best be classed as aspen-birch-conifer and aspen-birch-hardwoods.[3] We know that aspen comprised a large proportion of the timber volume in Minnesota in 1899 when Ayres (1900) estimated the aspen volume in the State as 34.2 million cords—equivalent to about 17 billion board feet—compared with the combined volumes of 16 billion board feet for red pine and white pine.

There is evidence from Michigan and Wisconsin that varying numbers of aspen trees were present in the pine, spruce–fir, swamp hardwoods, and northern hardwood types (Roth 1898, Cox 1914, Frothingham 1915, Truax 1915, Kenety 1917, Morbeck 1922, Stearns 1949, Graham *et al.* 1963). Thus, at the time pine logging began, aspen already was a component of several forest types over much of the Lake States; in Minnesota, it formed the dominant cover on extensive areas.

CURRENT SITUATION

The area of aspen forest has greatly increased since the time of early settlement. Logging of pine and other desirable timber was invariably followed by fire, sometimes accidental but often for land clearing or to eliminate hazardous slash. Slash burning was required by law in Minnesota for many years. These fires were widespread and frequently burned into uncut timber stands as well as previously burned areas. Aspen invaded some areas by means of its light, wind-dispersed seed; more important was the initiation of vigorous suckers from the roots of the fire-killed aspen trees in the stands. As a result, aspen became the dominant cover type in Lake States forests.

Area and Distribution

Aspen is the largest, most widely distributed forest type in the Lake States region where it occupies 26 percent of the commercial forest land (table 1). The aspen forest also extends across Canada and occupies sizable areas in the Northeastern States and the Rocky Mountains of Colorado and Utah.

According to the latest forest surveys, the three Lake States contain more than 13 million acres of commercial forest land in the aspen type. About 6 million acres are in public ownership, and nearly half of this land is in Minnesota (table 2). Only 6 percent is owned by forest industries. The balance, nearly 6½ million acres, is in farm and other private holdings.

The aspen forest is most prevalent in Minnesota, but Wisconsin and Michigan also have large acreages (fig. 1). Extensive areas of relatively unbroken aspen land occur in northern Minnesota, northwestern and north-central Wisconsin, and the south-central and eastern parts of the Upper Peninsula of Michigan. Elsewhere in the Lake States, the aspen type is limited to small areas interspersed with agricultural land and other forest types. Aspen also is a component of many other forest types.

---

[1]Respectively, former principal silviculturist and research forester, North Cent. For. Exp. Stn., USDA For. Serv., St. Paul, Minn. Both authors are now retired.

[2]Common and scientific names of plant species mentioned are given in Appendix I.

[3]"Original Forests of Minnesota," compiled from U.S. Land Office field notes by F. J. Marschner, Office of Agricultural Economics, for the Forest Service, U.S. Dep. Agric., 1930.

TABLE 1.—*Area of commercial forest land in the Lake States aspen type by States and stand-size classes*

State	Stand-size class[1]			Totals	Proportion of commercial forest land
	Saw-timber	Pole-timber	Seedlings and saplings		
	Thousand acres				*Percent*
Minnesota[2]	[3]284(5)	3,654(67)	1,513(28)	5,451(100)	32
Wisconsin[4]	139(4)	1,938(53)	1,588(43)	3,665(100)	25
Michigan[5]	345(8)	2,145(52)	1,639(40)	4,129(100)	22
All Lake States	768(6)	7,737(58)	4,740(36)	13,245(100)	26

[1]Stand-size class is based on d.b.h. of the predominant trees: sawtimber—11 inches and larger; poletimber—5 to 10 inches; seedlings and saplings—less than 5 inches.
[2]Stone 1966. Based on field survey begun in 1962.
[3]Figures in parentheses show percent of total.
[4]Spencer and Thorne 1972. Based on field survey begun in 1968.
[5]Chase *et al.* 1970. Based on field survey begun in 1966.

TABLE 2.—*Area of commercial aspen type by ownership class in the Lake States*

Ownership class	Area				Proportion of total			
	Minn.[1]	Mich.[2]	Wis.[3]	Three States	Minn.	Mich.	Wis.	Three States
	Thousand acres				*Percent*			
Public[4]	3,004	1,592	1,441	6,037	55	39	39	45
Industrial	173	307	303	783	3	7	8	6
Other private[5]	2,274	2,230	1,921	6,425	42	54	53	49
Totals	5,451	4,129	3,665	13,245	100	100	100	100

[1]Stone 1966. Based on field survey begun in 1962.
[2]Chase *et al.* 1970. Based on field survey begun in 1966.
[3]Spencer and Thorne 1972. Based on field survey begun in 1968.
[4]Includes Federal (Forest Service, Indian Affairs, Bureau of Land Management, and others), State, county, and municipal lands.
[5]Includes farmer-owned and other private lands.

Size and Age Classes

Over half of the area in the aspen type is occupied by poletimber stands, and 36 percent is stocked with seedlings or saplings (table 1). Only 6 percent of the type is occupied by sawtimber stands, although some of these are overmature. With reasonably good management, it should be possible to maintain a good balance of size classes over the region.

Most aspen stands in the Lake States are not mature—28 percent are less than 20 years old and 44 percent are 20 to 39 years old (Stone 1966, Chase *et al.* 1970, Spencer and Thorne 1972). About a fourth of the stands are 40 to 60 years old and most of these could be harvested for pulpwood or sawtimber. Although only 4 percent of the present stands are distinctly overaged, a large increase in the older age classes is expected within the next few decades because many stands probably will not be harvested for want of markets.

Volume

The aspen type also accounts for the greatest volume among species growing in the Lake States. Leuschner (1972) estimated that the volume of aspen growing stock was 7.5 billion cubic feet in 1968, about 23 percent of which was in forest types other than aspen.

During the periods between forest surveys, as shown in table 3, total growing-stock volume in-

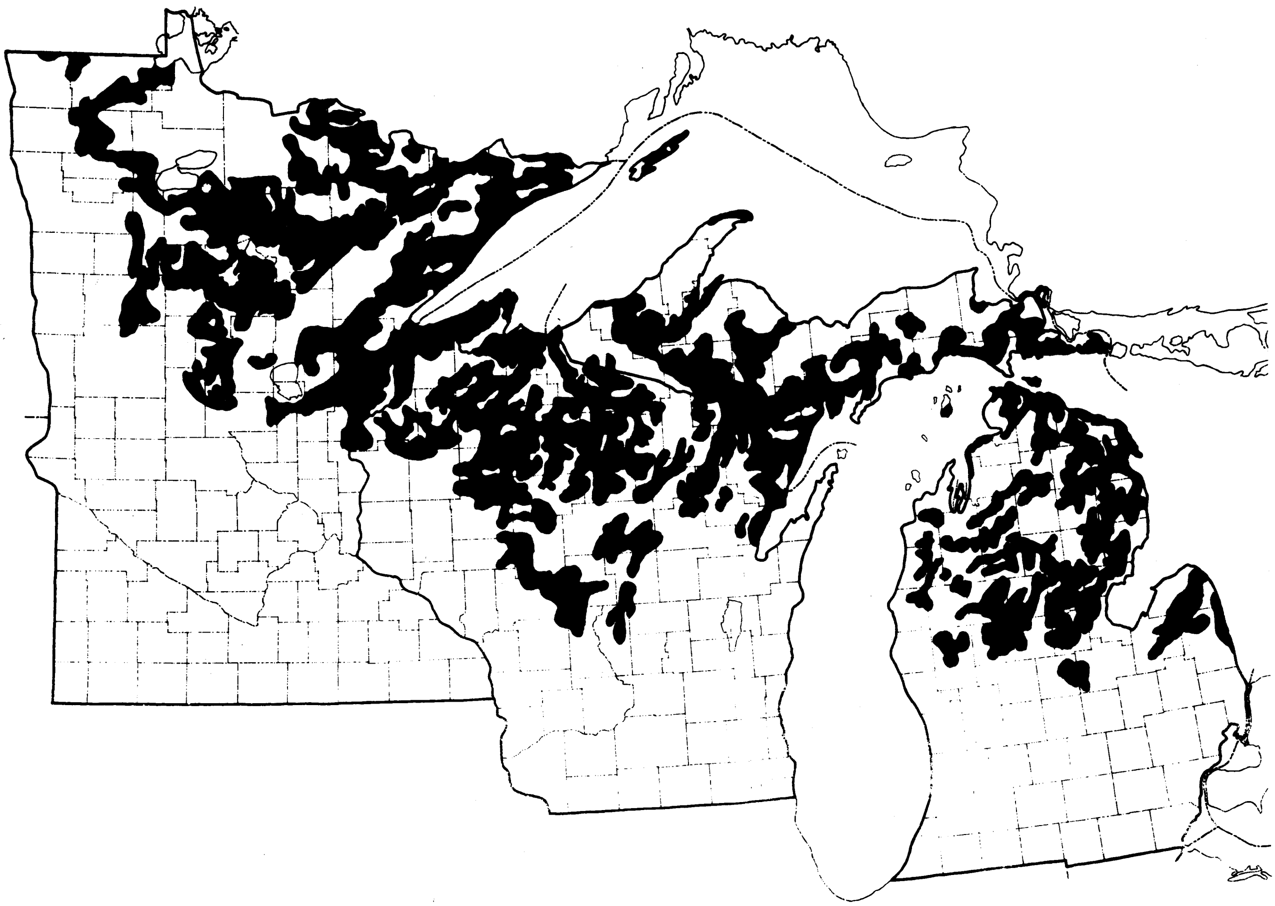


Figure 1.—Major areas of aspen land in the Lake States.

TABLE 3.—*Net volume of aspen sawtimber and growing stock on commercial forest land in the Lake States, and increases in volume between periodic forest surveys; data include both aspen species*

State	Year survey began	Sawtimber	Increase	Growing stock	Increase
		Million fbm[1]		*Million ft*^{3}[2]	
Minnesota	1953[3]	1,716		1,812.0	
	1962[3]	2,388	672	3,088.2	1,206.2
Michigan	1955[4]	1,174		1,779.0	
	1966[5]	2,684	1,510	2,257.1	478.1
Wisconsin	1956[6]	813		1,649.9	
	1968[7]	2,109	1,296	2,159.5	509.6

[1]International ¼-inch rule to a 9-inch top diameter outside bark.

[2]Cubic-foot volume to a 4-inch top outside bark of sawtimber and poletimber trees. Divide values by 79 to convert to solid wood cords.

[3]Stone 1966.

[4]Findell *et al.* 1960.

[5]Chase *et al.* 1970.

[6]Stone and Thorne 1961.

[7]Spencer and Thorne 1972.

creased 40 percent. In Minnesota, the increase was 66 percent in 9 years, about 7 percent per year. Better markets for aspen reduced net volume growth in Wisconsin and Michigan, and local shortages have been reported. For the Region as a whole, however, the data indicate a net growing-stock increase of over 2 million cubic feet in the intervals between forest surveys.

In the Lake States, aspen sawtimber volume nearly doubled in a decade, faster in Wisconsin than elsewhere. Most of the aspen growing stock consists of trees in the 5- to 9-inch diameter classes, so the trend toward larger trees is expected to continue for some time.

Although quaking aspen predominates in the aspen types, bigtooth aspen may be locally abundant. It is the dominant species on 9 percent of the aspen land on State forests in the eastern part of the Upper Peninsula (Mich. Conserv. Dep., unpublished data) and equal volumes of the two species were found in lower Michigan (Chase *et al.* 1970).

Bigtooth aspen grows on a somewhat narrower range of sites than quaking aspen, and it seldom is found on the driest sites or on wet sites, such as swamp margins. When the two aspens grow side by side, most bigtooth trees outgrow quaking aspen trees (Graham *et al.* 1963).

Utilization

Aspens are relatively fast-growing, short-lived trees. On dry or excessively wet sites, they barely attain pulpwood size at maturity, but they can produce high-quality saw logs on the best sites. Aspen trees reach physiological maturity on most sites before they reach saw log size (fig. 2). Thus, the major use of aspen is for pulp or chipboard.

Because of the relative scarcity of the more valuable softwoods, the use of aspen for these products has greatly increased, and this trend is continuing. Aspen provided more than half of the total reported pulpwood cut of the Region in 1969; the paper industry used 2 million cords, more than three times as much as pine (Blyth 1970). In spite of this increasing demand, however, volume growth of aspen continues to exceed consumption. The present volume is about 40 percent greater than it was 10 years ago, and probably is adequate to supply anticipated industry needs for about two decades.

F-522789

Figure 2.—A typical quaking aspen stand nearing maturity.

The current harvest or removal of aspen falls short of that necessary to offset its rapid growth—the annual desirable or allowable cut (table 4). Although no recent data are available, this seems especially true in Minnesota. Growth and removal are more nearly in balance in Wisconsin and Michigan because the supply is closer to the pulpmills and papermills.

TABLE 4.—*Relation of actual removal[1] of aspen growing stock on commercial forest land to the annual desirable cut in the Lake states*

State	Annual desirable cut	Actual removals	
		Amount	Proportion of desirable cut
	Thousand cords	*Thousand cords*	*Percent*
Minnesota[2]	1,632	527	32
Michigan[3]	1,050	864	82
Wisconsin[4]	816	1,109	136
Total	3,498	2,500	72

[1]Removals in Michigan and Wisconsin include volumes "lost" to land clearing, cultural operations, and changes in land use.
[2]Stone 1966. Based on field survey begun in 1962.
[3]Chase *et al.* 1970. Based on field survey begun in 1966.
[4]North Central Forest Experiment Station unpublished data.

FUTURE OF THE ASPEN FOREST

During the next 20 years, the area in aspen forest is expected to decrease. Some aspen land is being cleared for pasture or cropland. Other areas will be used for new roads and utility lines, and a limited acreage will be planted with conifers. The greatest reduction in the aspen type will result from aspen stands being allowed to convert naturally to the more tolerant hardwoods and conifers.

Because the understories of most aspen stands are dominated by other species, Heinselman (1954) predicted widespread conversion of aspen to other forest types unless the natural succession is interrupted by cuttings, fire, or other disturbance. A third of the aspen type could be completely replaced by more permanent forest types, and partial conversion could occur on another 14 percent of the aspen area. Successional trends are toward northern hardwoods, spruce-fir, ash-elm, oak, swamp conifers, and pine types in decreasing order of importance.

Despite this expected loss, aspen volume may be even greater 20 years hence than at present. The imbalance of actual versus desirable cut is expected to continue for some time; in part because additional ingrowth will occur on the large area of seedling and sapling-sized stands, which now total about 4.7 million acres in the three States.

Improved markets for aspen wood and increasing awareness of the other values of aspen stands are expected to result in better management of the resource. Opportunities for profitable aspen management will be enhanced where both saw logs and pulpwood can be sold. Meeting other objectives such as improving wildlife habitat or esthetic values also may be important.

Because of its abundance and relatively short-fibered pulp, aspen pulpwood has brought a lower price than that of some other species. This situation is changing because better markets are developing for aspen, not only because of lower raw material costs but also because the kraft process used in pulping hardwoods creates fewer pollution problems. Several sulphite mills have closed while kraft-mill capacity is expanding in the Lake States.

Use of aspen by the housing industry will undoubtedly increase if an adequate supply of large, sound logs becomes available. The recent decision to grade aspen lumber under softwood rules has already created increased demands for aspen saw logs. A number of new mills have been built to use aspen, and the capacity of others is being increased.

Although the better grades of aspen lumber are easily sold, most logs are too small to produce much of this material (Zasada 1948). An aspen grade yield study made at Red Lake, Minnesota, showed that saw logs with scaling diameters of 8 to 12 inches yielded lumber grading about 85 percent No. 2 or No. 3 Common.[4] In contrast, 45 percent of the

[4]USDA Forest Service. Unpublished results are on file at the Northeast. For. Exp. Stn., Upper Darby, Pa.

lumber sawn from larger (13- to 18-inch) logs was in No. 1 Common or better grades. Their study included logs of both bigtooth and quaking aspens, but large logs of both species produced similar percentage yields of the higher grade lumber (or veneer).

The choice logs come from large trees that now are found in appreciable numbers only in overmature stands where cull is high. Thus, high-quality logs form only a small proportion of those cut from present stands. If larger, high-quality trees could be grown in shorter rotations, decay and other defects would be minimal. The results of management studies (described later) indicate that this can be achieved, at least on the better aspen sites.

ASPEN'S ROLE IN MAINTAINING OTHER RESOURCES

The aspen forests of the Lake States also are valuable because they contribute to other important resources. The aspen type and its associated vegetation furnish food and cover for many forms of wildlife. In the Central Rocky Mountain Region, aspen suckers provide valuable browse for sheep, but aspen areas are seldom used for this purpose in the Lake States. Because they regenerate promptly after logging or fire, the aspens help stabilize the water regime of streams and lakes. Furthermore, aspen forests have considerable esthetic and recreation values.

Wildlife

In the aspen type, the objectives of producing both timber and wildlife are fully compatible because the clearcutting necessary to perpetuate aspen results in highly desirable habitat for deer, moose, and grouse. To meet timber, wildlife, and esthetic objectives, aspen management should provide for clearcutting numerous small, well-dispersed areas each year. This will produce vigorous aspen stands with the wide range in age classes needed for maximum production of grouse. Young sprout stands are utilized by deer and moose throughout most of the year.

Deer and Moose

Aspen suckers are a favored winter food of moose (*Alces americana*) (Aldous and Krefting 1946), and are heavily browsed by white-tailed deer (*Odecoileus virginiana*). Aspen once was considered relatively unimportant as deer food in the Lake States because of an abundance of more palatable browse (Aldous and Smith 1939). It is now recognized that numerous, well-distributed small clearcuttings in aspen stands will provide the browse and the forbs essential for maintaining good deer populations (Rutske 1969).

The most important deer-producing areas in Michigan are those where the aspen types predominate (Byelich *et al.* 1972). In Wisconsin, McCaffery and Creed (1969) found consistently higher deer activity during the summer months in aspen than in northern hardwood forests. Their studies showed that numerous small, permanent openings in stands growing on loamy soils provided highly preferred summer deer habitat, but they concluded that such openings were difficult to establish and maintain because these better soils usually are invaded by northern hardwoods. In contrast, natural openings are relatively abundant and stable on the sandy soils where aspen, oaks, and pines predominate. These forest types commonly provide substantial levels of high quality deer food during their entire rotations.

The management practices necessary for growing repeated crops of aspen also create conditions that benefit deer and moose—an abundance of aspen suckers is available for the first 5 years after clearcutting (Rutske 1969). In contrast, overmature stands provide little usable browse and forbs for these animals. If such stands are not harvested, they often are succeeded by more shade-tolerant forest types that are less valuable for deer and moose habitat.

Even where there is a poor market for aspen, existing needs for wildlife habitat and expected future needs for wood and fiber often justify a cooperative program of planned clearcuttings by wildlife and timber managers. Because the species remaining after commercial logging in the aspen type may hinder sucker development, wildlife funds are being used to maintain and renew potentially productive deer range. Byelich *et al.* (1972) reported that 12,000 acres in the aspen-birch type were treated in Minnesota in 1969 and 1970; Wisconsin cut about 22,000 acres in 1969. Between 1958 and 1969, about 69 square miles of aspen, aspen-birch, and other aspen types in Michigan were cut or sheared with bulldozers to improve deer range. These cuttings usually were located near deer yards and were designed to stimulate sprout growth of aspens and associated species. However, wildlife managers generally agree that the area cut specifically for deer habitat is far less than that needed to improve deer populations enough to meet demands of the public.

In 1971, Michigan increased charges for deer licenses to fund an intensified program of deer habitat management. The objectives are to reverse the downward trend of deer populations and to increase the herd to 25 or 30 deer per square mile. The program will emphasize preservation, improvement, and expansion of the aspen type. A combination of commercial harvest cuttings and prescribed treatments will be used to provide an equitable distribution of tree size classes. Present plans are to treat about 400,000 acres within the next 10 years.

Beaver

The bark, leaves, twigs, and branches of aspen are preferred by beaver (*Castor canadensis*) to those of all other tree species in the Lake States. Beavers will "cut" aspens as far as 400 feet away from water, and will take trees of any size if necessary. A study in Michigan showed that an average beaver colony requires from 0.4 to 1.0 acre of aspen timber a year (Bradt 1947).

Ruffed Grouse

No other species of tree or shrub seem to fill the food and shelter need of ruffed grouse (*Bonasa umbellus*) as well as quaking and bigtooth aspens (Gullion and Svoboda 1972). In North America, distributions of these aspens and of grouse generally coincide. Although grouse can persist in warmer climates in the absence of aspen, the birds seldom are as abundant as in the northern areas where aspens are or have been an important component of the forest cover.

Gullion and Svoboda (1972) summarized results of long-term studies of aspen–birch relationships in Minnesota. Aspen leaves and staminate flower buds provided the most important year-long food resource. During the winter, grouse fed on the staminate flower buds of aspen six times as much as on buds of all other hardwood species combined.

The nutrient-rich male flower buds of aspen are available when snow covers the ground. During the coldest part of winter, grouse usually stay buried under the snow almost continuously, emerging only for a brief evening feeding period. In 15 to 20 minutes, the birds can consume enough of the easily-detached aspen buds to satisfy their daily food needs. This short feeding period minimizes exposure to predators such as owls and thus reduces winter losses of grouse. However, heavy use of staminate flower buds actually begins many weeks before snow covers the ground, and at least the male grouse continue to prefer the developing staminate catkins of aspen well into spring, long after snow melt.

Aspen leaves are a primary source of summer food, and a variety of aspen age classes provides the kind of habitat needed by grouse throughout their life cycle (Bump *et al.* 1947; Ediminster 1947; Gullion 1967, 1969). Newly regenerated aspen stands provide high quality brood habitat for hens and their chicks for perhaps a decade. Sapling and small pole stands provide good winter cover for birds of all ages, and may support a breeding grouse per 3 or 4 acres. Older stands provide a winter-long food resource and are often used by nesting hens, especially where the hens can fly directly to male aspen trees where they feed on new-grown leaves.

Where producing ruffed grouse for recreational hunting is a major objective, Gullion and Svoboda (1972) suggest that aspen management should provide stands of at least three age classes near each 10-acre breeding activity center. This could be achieved by growing aspen on 40 to 50 year rotations, harvesting the trees by clearcutting no more than 10 out of any 40 acres at one time and spacing the logging at about 10-year intervals.

Soil and Water

The aspens are unique in their ability to stabilize soil and watershed conditions. Fire-killed stands are promptly replaced by abundant root sprouts. The trees produce abundant leaf litter that contains more nitrogen, phosphorus, potash, and calcium than leaf litter from most other hardwoods. The litter decays rapidly, forming nutrient-rich humus that may amount to 25 tons per acre (oven-dry weight basis) (Stoeckeler 1961).

Because it readily absorbs moisture from rainfall and snowmelt, the humus layer reduces runoff and aids percolation and recharge of the ground water. This humus and leaf litter serve as a mulch to reduce evaporation from the surface of the mineral soil.

More snow accumulates under aspen stands, so the soil does not freeze as deeply as under pine or spruce forests (Weitzman and Bay 1963). Snowmelt begins earlier in the spring under the leafless aspens (Weitzman and Bay 1959) (fig. 3), and the

F-487809

Figure 3.—Snow begins to melt by mid-April in aspen stands.

frozen ground thaws sooner, permitting more rapid infiltration of the melted snow.

In northern Minnesota, Verry (1972) found that clearcutting aspen stands temporarily increased total water yields and hastened snowmelt in the spring. Peak water yields occurred a few days earlier in clearcut areas but water quality was not adversely affected.

Recreation

Although aspen stands have only limited scenic appeal during most of the year, they are a primary attraction for visitors to the north country during autumn. The varying blends of aspen's golden foliage and whitish bark with the dark greens of conifers and the vivid colors of other hardwoods provide spectacular vistas that are enjoyed by thousands each year.

Aspen sites may make poor campgrounds, however, because they seem to be a favorable habitat for mosquitoes and black flies. Trampling and disturbance by campers may lead to early mortality of an aspen stand, so areas stocked with other species are apt to make more durable campgrounds.

The most important recreational value of aspen stands results from the desirable wildlife habitat they provide. There are many opportunities for the visitor to hunt deer, moose, and grouse and to see these and other wildlife where vigorous aspen stands are maintained in a variety of age classes.

SILVICAL CHARACTERISTICS

The aspens are unique in that almost all stands originate as suckers that arise from existing root systems. Seedlings seldom are numerous enough to form a stand, but seedling reproduction has enabled aspen to invade many new areas after fire or logging. Because aspen seedlings grow faster than any associated species except pin cherry, a few seedlings can persist to form the nucleus of a new stand that is expanded by root sucker production after fires occur.

Seedling Reproduction

Although abundant seed is produced, both quaking aspen and bigtooth aspen reproduce from seed only under favorable conditions. The scarcity of seedling reproduction has been attributed to various factors: the short duration of seed viability; presence of a germination and growth inhibitor in the "seed hair"; unsuitable seedbeds during the crucial establishment period; or seedling losses to disease, insects, or drought (Maini 1960).

Seed Production

Aspen trees start flowering when they are about 10 years old and produce some seed nearly every year thereafter. Both flowers and trees are normally unisexual, but a few perfect flowers are produced on some trees. Because most aspens originate as root suckers, the stands usually are a mixture of male and female clones consisting of a few to several hundred trees. Clonal differences are most evident in the spring, when trees of some clones can be seen leafing out while adjacent trees are still dormant.

In the Lake States, aspen seed is shed over a 3-week period during early May to mid-June, beginning earliest on protected sites and in the southern portion of the region. The tiny aspen seeds (2.5 million per pound) are carried long distances by the wind (Maini 1972). Good seed crops are borne about every 5 years.

Seedling Establishment

Viability of freshly fallen seed normally exceeds 90 percent (USDA Forest Service 1974) and is retained up to 3 weeks (Kittredge and Gevorkiantz 1929). On moist seedbeds, germination begins within 12 hours after seed fall and is completed in a day or two.

Establishment of seedlings requires an exact combination of environmental conditions. Bare mineral soil, particularly recently burned land, forms the best seedbed. Seedling survival and initial development require the maintenance of a moist soil for several days—if the surface dries out, the seedling will die. During this critical stage and for some time thereafter the seedlings can also be killed by heat, fungi, competing vegetation, and heavy rains.

Seedlings may reach 6 to 24 inches in height by the end of their first year and have roots extending 6 to 10 inches in depth and up to 16 inches laterally (Shirley 1941, Day 1944). Although their root systems develop rapidly, seedlings make little height growth until they are about 3 years old. Such established seedlings are capable of producing a few suckers after fire or other disturbance (Day 1944, Steneker 1972).

Reproduction from Suckers

Aspen stands continually produce weak, inconspicuous suckers, most of which live only a few years. After a stand is logged or killed-back by fire, however, so many suckers arise that a new aspen stand is virtually inevitable. In the Lake States, from 3,500 to 22,850 suckers per acre have been reported 1 year after logging (Kittredge and Gevorkiantz 1929, Zehngraff 1946, Strothmann and Heinselman 1957, Graham *et al.* 1963). Most sprouts arise from small lateral roots located within 3 inches of the soil surface, predominantly in the humus layer and the upper part of the mineral soil (Farmer 1962b, Sandberg and Schneider 1953). This continuous reserve of suckers plus the ability to produce many vigorous new suckers help explain aspen's rapid dominance of cutover and burned lands in the Lake States.

Another factor favoring abundant sucker development is the wide distribution of aspen's shallow root system. Although most suckers arise within 25 feet of cut trees, suckers have been found over 100 feet from the parent tree (Buell and Buell 1959).

Suckers soon develop many feeding roots which supplement the parent root system and facilitate rapid growth. Some of the suckers may remain attached to the parent roots for years; others gradually become separated as the old roots decay. There is no evidence that decay of the parent roots of quaking aspen has any adverse effect on individual trees.

Interconnected root systems may persist as long as 90 years (Quaite 1953). Thus, most stands of quaking aspen, like bigtooth aspen (DeByle 1964, Barnes 1966), contain groups of trees having a common root system.

Because they develop on established root systems, quaking aspen suckers grow faster than seedlings. Under full light, suckers will reach a height of 3 to 4 feet or more by the end of the first full growing season (Zehngraff 1947) and 10 to 15 feet after 5 years.

Factors Affecting Suckering

Aspen root suckering is largely controlled by apical dominance; cutting or killing the overstory tree interrupts the flow of growth regulators from the stem to the roots (Farmer 1962a, Steneker 1972). Thus, dormant buds on all root systems are free to develop in clearcut areas. The exposed soils in such areas often reach 75 to 80° F which further stimulates sucker production (Maini and Horton 1966).

The most important of several factors affecting the production and development of quaking aspen suckers is the proportion of the stand left after logging or fire. Where only part of the stand is cut or killed, sucker production will be stimulated on fewer root systems. Suckers arising after such partial cuttings often grow slowly and some are killed because of the competition and shade provided by the remaining trees and the brush characteristic of many aspen stands (Zehngraff 1949). Occasionally, underbrush is so dense that no suckers develop (Ghent 1958). The best sucker production and development follows either complete clearcutting or a burn that kills all of the parent trees and brush (fig. 4).

The density of the parent stand before cutting also appears to affect sucker production. In Michigan, 1 year after clearcutting there were 5,200 suckers per acre in quaking aspen stands where basal areas had been less than 50 square feet, 7,000 suckers per acre in stands where the basal area had ranged from 51 to 100 square feet, and 9,900 suckers per acre in stands where the basal area had been over 100 square feet (Graham *et al.* 1963). In Minnesota, suckering was found to be most abundant

F-439548

Figure 4.—This 10-year-old stand of aspen suckers developed after a complete clearcutting. There are about 4,800 stems per acre.

following removal of stands having a basal area of 80 or more square feet per acre (Sandberg and Schneider 1953).

Sucker production also is related to clonal differences. In lower Michigan, Utah, and Manitoba, some quaking aspen clones were found to sucker more abundantly than others (Farmer 1962a, Maini 1967, Steneker 1972, Tew 1970).

Evidence on the effect of parent stand age on sucker production is conflicting. Stoeckeler and Macon (1956) found that sucker production increased to age 50, although Graham *et al.* (1963) concluded that peak production occurred at age 35. However, age appears to have little practical significance; where stands are clearcut, quaking aspen will produce an abundance of suckers over its whole lifespan.

Season of cutting affects the number and vigor of aspen suckers (Steneker 1972). Zehngraff (1946) found that winter logging resulted in at least four times as many suckers as did summer or spring logging; differences in sucker production were less where stands were logged in late summer (Stoeckeler and Macon 1956).

Winter logging results in more vigorous suckers because they appear the following summer, get an equal start with the released brush, and soon outgrow it. Sprouts arising after spring cuttings still may be growing in the fall and are often killed-back by freezing. Sprouts following summer cuttings do not appear until the second season after competing brush has had a year to develop. For practical purposes, however, stands can be harvested in any season if a complete clearcut is achieved because adequate sprouts will arise to ensure a new aspen stand.

Sucker production is also influenced by fire intensity. A moderate burn that kills the aspen tops and undergrowth and destroys the litter and part of the duff will produce more suckers than either a light or severe fire (Horton and Hopkins 1965). A succession of infrequent fires will increase the density of sucker stands (Kittredge 1938, Shirley 1941), but annual fires may eliminate the suckers because the depleted food reserves in the roots have little opportunity to be replaced (Gates 1930, Buckman and Blankenship 1965).

Saplings to Maturity

Reaction to Competition

Quaking aspen is more intolerent of shade than any other important coniferous or deciduous tree species found in the Lake States (Baker 1949, Graham 1954). Because it is intolerant, aspen prunes well in closed stands, and has pronounced ability to express dominance even in overstocked stands (Kittredge and Gevorkiantz 1929). Aspens require nearly full light for satisfactory survival and growth; overstory trees left after logging or fire restrict development of the young aspen.

Because they most often invade land once occupied by other forest types, quaking aspen stands have no characteristic underbrush or ground cover

(Roe 1935). Instead, such vegetation is mostly composed of the species whose underground parts are able to survive fire and therefore persist for many years. In the Lake States, the following shrub species are most common in aspen stands: beaked hazel, dwarf bush honeysuckle, mountain maple, common chokecherry, alder, raspberry, and blackberry. Herbaceous vegetation may include bigleaf aster, wild sarsaparilla, Canada beadruby, dwarf red blackberry, bunchberry dogwood, yellow beadlily, roughleaf ricegrass, sweetscented bedstraw, strawberry, spreading dogbane, fireweed, rosy twistedstalk, early meadowrue, sedges, goldenrods, sweet-fern, and lady fern.

The composition and development of brush and ground cover varies with site quality. The richer sites typically have a tall, dense undergrowth that offers serious competition to the intolerant aspen suckers. On the poorer sites, the undergrowth is relatively sparse and short.

Growth and Mortality

Height growth of root suckers is especially rapid after the first few years. On the better sites, dominant trees attain heights of 25 feet in 13 years, 37 feet in 20 years (Shirley 1941), and 70 to 80 feet in 50 years (Kittredge and Gevorkiantz 1929). Subsequent growth is slower, and the stands ultimately deteriorate because of decay and attendant breakage. By the time most Lake States stands are 80 to 100 years old, only a few decadent trees remain. On the poorer sites, however, the stands may begin to show decadence at about 25 years of age (Schantz-Hansen 1945). Overmature aspen stands tend to be succeeded by brush or other tree species because vigorous suckers do not develop unless the aspens are cut.

Longevity and Sizes Attained

Although quaking aspen is considered a short-lived species, individual trees may persist for a long time. Heinselman (1973) suggested that some aspen trees in northern Minnesota probably survive for 150 to 200 years. Trees 130 to 140 years old were found in northern Michigan (Graham *et al.* 1963), and trees 170 to 180 years old were reported in Canada (Kirby *et al.* 1957, Basham 1960).

Aspens up to 45 inches d.b.h. and 100 feet in height have been found in Saskatchewan.[5] In the Lake States, the largest known diameter is 38 inches and the tallest tree is 110 feet in height; both trees were found in northern Minnesota. Trees in mature stands range from 65 to 80 feet in height; maximum diameters of 15 to 16 inches are attained but average stand diameter seldom exceeds about 12 inches.

Farther east and near the southern edge of the range of aspen in the Lake States, the trees do not grow as large or live as long as in Minnesota and northward. The heart rots that eventually result in cull trees apparently develop more rapidly in southern than in northern latitudes (Graham *et al.* 1963). Thus, the recommended maximum rotation age is 65 to 80 years in eastern Canada and the Prairie Provinces (Kirby *et al.* 1957, Jarvis 1968) compared with 35 to 60 years in the northern Lake States (Zehngraff 1947, 1949) and 35 to 45 years in lower Michigan (Graham *et al.* 1963).

Occurrence in Pure and Mixed Stands

Quaking aspen may occur in essentially pure stands but aspen also grows with many other tree species. Common associates in northern Minnesota and Canada are paper birch, jack pine, balsam fir, white spruce, black spruce, northern white-cedar, black ash, and balsam poplar. Farther south and east, aspen may grow with sugar maple, red maple, basswood, white ash, northern red oak, bur oak, paper birch, yellow birch, bigtooth aspen, pin cherry, red pine, and eastern white pine.

The associated species may occur in the upper crown canopy or form a definite understory that is released to become the dominant forest type after death or harvest of the aspen. In most areas, this established understory is dominated by the more tolerant species—sugar and red maples, northern red oak, bur oak, balsam fir, white spruce, eastern white pine, northern white-cedar, and black spruce. The presence of these species as an understory is responsible for the large amount of natural conversion taking place in the aspen forest of the Lake States.

Role in Forest Succession

Under favorable conditions, quaking aspen seedlings will gain a foothold on sites where they did not grow before, particularly after fires, logging, or windstorms. Even where aspen was only a minor component of disturbed stands, its suckers often dominate the site after a succession of fires. And where aspen was already dominant, logging or natural catastrophe can perpetuate it.

[5]Personal report from J. B. Prince, Saskatchewan Office of Industrial Development, Regina.

Because of its abundant windblown seed and aggressive suckers, aspen can become the dominant species on sites formerly occupied by other hardwoods or conifers. In northwestern Minnesota, north-central North Dakota, and the Prairie Provinces of Canada, grasslands often are invaded by aspen suckers. If not held in check by mowing or burning, these suckers form semipermanent groves (Ewing 1924, Buell and Buell 1959, Maini 1960).

Aspen cannot reproduce successfully under its own shade, so it forms a relatively short-lived temporary forest type that can readily be invaded and eventually dominated by more shade-tolerant species (fig. 5). Soil moisture and fertility strongly influence the ecological succession. On dry sites, aspen may be replaced by red pine, red maple, or oaks; on sites with intermediate moisture, by white pine; and on moist fertile sites, by northern hardwoods, white spruce, and balsam fir. Succession on the wettest sites is toward balsam fir, black spruce, black ash, and northern white-cedar, but brushy species often form a semipermanent type on these wetter sites.

The rate of natural conversion is most rapid on the better sites and varies with the aggressiveness and growth rate of the invading species. On some sites, conversion is a slow process and aspen persists for several generations even in the absence of fire.

Sugar maple and balsam fir grow more rapidly under a full aspen cover than do pines, partly because of their greater tolerance and partly because they tend to invade better sites. Hence, the succession to hardwood or spruce–fir types normally occurs at a more rapid rate than that from aspen to pines. In northern lower Michigan, conversion of aspen to sugar maple-beech may require 20 to 35 years as compared to 30 or 40 years for pine (Gates 1930).

F-385067

Figure 5.—Stand of 50-year-old aspen converting naturally to balsam fir and black spruce.

Clones and Hybrids

Although limited, there is evidence that quaking aspen, like other species of wide geographic range, has probably developed clones that are adapted to local climates. In Saskatchewan, seedlings of local origin have heavier root systems and stop growing earlier in the fall than seedlings from Wisconsin (Vaartaja 1960). Two distinct forms exist in Utah and Colorado; one attains full leaf development 2 to 3 weeks earlier than the other and is dominant at higher elevations (Baker 1921, Cottam 1954). These may be clones that are extensive in range because they also differ in time of leaf fall, bark color, and abundance of staminate flowers.

In the Lake States, most aspen stands are composed of intermingled clones; each may consist of from one to hundreds of stems. Single clones may occupy as much as 3.8 acres (Steneker 1972) but the typical range is from 0.05 to 0.2 acre (Barnes 1966). Millions of clones probably exist within an area the size of the Lake States. For example, Barnes (1959) found 31 different quaking aspen clones in stands on two relatively uniform sites in northern lower Michigan. These clones showed distinct differences in leaf shape, time of leafing, fall coloration, bark, stem form, suckering ability, or growth capacity. Studies of clones from northern Wisconsin and the Upper Peninsula revealed similar interclonal variations as well as differences in wood-fiber length, in specific gravity, and in the characteristics of the paper made from the fibers (Buijtenen *et al.* 1959, 1962).

As in other species of the genus *Populus*, most cells of quaking aspen clones are diploid; they contain two sets of 19 chromosomes each (Joranson 1953). However, three small clones containing three sets of chromosomes have been found in the Lake States. These triploid clones grow faster and produce better fiber than do the usual diploid clones, so they seem to offer considerable promise in aspen breeding (Buijtenen *et al.* 1958).

Some clones are distinctly above average in form, quality, and growth rate (fig. 6). However, the poor suckering ability of some of these clones can result in inadequate regeneration following cutting (Garrett and Zahner 1964, Tew 1970). As aspen management becomes more intensive, more efforts probably will be made to favor outstanding clones that can be readily identified.

Although the species usually do not flower at the same time, hybrids of bigtooth and quaking aspen have been found in lower Michigan (Barnes 1961), in Minnesota (Pauley 1956), and in eastern Canada (Marie-Victorin 1930). Both aspens hybridize naturally with white poplar (Peto 1938, Little *et al.* 1957). Artificial crosses have been made of quaking aspen with white poplar, bigtooth aspen, and European aspen (Heimburger 1936, 1940). Some hybrids with European aspen have shown excellent quality and growth rate (Church 1963, Pauley *et al.* 1963, Einspahr and Benson 1964).

F-506157

Figure 6.—Superior clone of aspen showing good form and growth rate. The trees are about 60 years old.

SOIL AND SITES

In the Lake States, quaking aspen grows on a wide range of soils—on infertile dry sands (as scattered trees), on rich loams, on heavy clays, and on waterlogged mineral soils and peats. Aspen also forms stands in the ledge rock area (Laurentian Shield) of northeastern Minnesota.

Growth rate varies with soil fertility and available moisture. Moist fertile loams can produce large saw log- and veneer-quality aspens, but deep dry sands and some rocky areas will produce only limited yields of pulpwood.

Because most Lake States soils are of glacial origin, site quality of aspen may vary considerably within short distances. However, there are large areas where the sites are relatively uniform. Some of the best sites are on the heavy-textured high-lime soils of glacial Lake Agassiz and the surrounding territory in northwestern Minnesota. Poor sites predominate in the gravelly moraines found in north-central Wisconsin and in east-central Minnesota, and the lacustrine red clay belt of northwestern Wisconsin and western upper Michigan (Kittredge and Gevorkiantz 1929, Stoeckeler 1960).

Aspen grows slowly on sandy soils because of low moisture and nutrient levels. The slow internal drainage and insufficient aeration of clay soils also restrict growth rates (Stoeckeler 1960). Growth on sandy soils is somewhat better where the water table is between 18 and 60 inches deep, but a higher water table appears to be detrimental (Wilde and Zicker 1948, Wilde and Pronin 1950).

The availability of soil nutrients also influences growth rate. Average annual growth of quaking aspen on soils containing high levels of Ca, Mg, K, and N was more than four times that on soils in which the levels of these elements were low (Voigt *et al.* 1957). Stands growing on soils containing an abundance of calcium carbonate had a site index 10 feet higher than that of stands on the more acid soils (Stoeckeler 1961).

Site Classification Based on Height Growth

To facilitate the estimation of aspen site quality, particularly where this is not readily apparent as in young stands, Kittredge and Gevorkiantz (1929) prepared a set of site index curves that were revised by Gevorkiantz in 1956 (fig. 7). These curves are based on the height of the average dominant trees at or projected to 50 years and segregate aspen sites into five classes ranging from very poor (S. I. 40) to excellent (S.I. 80). The revised curves are generally adequate for use in the Lake States except on the sandy soils of the eastern Upper Peninsula and northern lower Michigan, which were not sampled.[6] Graham *et al.* (1963) prepared site index curves and yield tables for quaking aspen in northern lower Michigan based on height attained at 30 instead of 50 years.

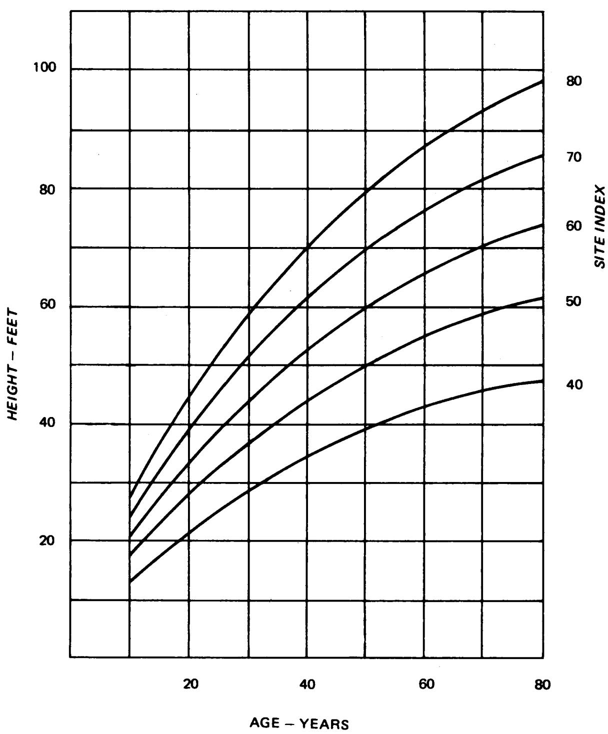


Figure 7.—Site index curves for quaking aspen. (Adapted from Kittredge and Gevorkiantz 1929 by Gevorkiantz 1956.)

Site Classification by Soil, Topography, and Vegetation

Many attempts have been made to classify quaking aspen sites on the basis of their soil characteristics and understory vegetation. Heinselman and Zasada (1955) concluded that aspen site quality was determined by the interaction of many environmental factors. The most important of these were soil texture and fertility, ground water, and topography.

The site prediction scheme for aspen shown in table 5 was developed by Strothmann (1960). It is based on soil characteristics (texture of the upper 36 inches of the profile, acidity, and water table depth) and on topographic characteristics (aspect, slope, and position on slope) (tables 6 and 7). Strothmann omitted fire history in this scheme because he found it had no measurable effect on site quality. He also found that site quality tended to improve as subsoil pH increased on fine-textured soils having deep water tables.

Plant indicators appear to have limited value for estimating aspen site quality (Kittredge 1938, Roe 1935, Sisam 1938). In general, site quality was excellent where understory vegetation associated with the northern or bottomland hardwood types was found under aspen stands, but where an understory typical of red pine or jack pine types occurred, the aspen was slow growing. Understories usually found in oak, spruce-fir, and white pine stands indicated sites of intermediate quality. Thus understory vegetation might be used in conjunction with soil characteristics in a regional classification of aspen sites.

Soil-site relationships in aspen may be confounded by clonal variations. Steneker (1972) found significant differences in the total heights of quaking aspen clones that grew together. In lower Michigan, trees of some bigtooth aspen clones were as much as 24 feet taller than those of other clones on the same site (Zahner and Crawford 1965). Clonal variations of this magnitude would seriously affect the accuracy of site index determinations.

[6]Similar site index curves have been prepared for aspen in northern Ontario (Plonski 1956) and Saskatchewan (Kirby *et al.* 1957).

TABLE 5.—*Aspen site prediction scheme combining soil and topography ratings (based on 235 plots)*

Topography rating[1]	Soil rating[2]	Site index			Plots
		Average	Highest	Lowest	
					No.
On sloping land:					
Favorable	Excellent	86	90	83	2
	Good	78	97	59	13
	Fair	74	74	74	1
	Poor	—	—	—	0
Average	Excellent	76	85	60	7
	Good	69	77	57	12
	Fair	66	87	52	10
	Poor	—	—	—	0
Unfavorable	Excellent	72	79	68	3
	Good	68	76	61	10
	Fair	59	72	50	4
	Poor	44	45	43	2
On flat land:[3]	Excellent	74	90	57	63
	Good	70	91	57	46
	Fair	66	82	53	52
	Poor	57	70	50	10

[1]See table 7 for descriptions of topography ratings.
[2]See table 6 for descriptions of soil ratings.
[3]Having slope of less than 5 percent.

TABLE 6.—*Rating of soil factors*[1]

Soil rating	Stone content[2]	Silt plus clay content[2]	Depth to water table
	Percent	*Percent*	*Inches*
Poor	0–30	0–9	60+
Fair		0–9	0–60
Fair		10–20	0–60
Good		21–30	0–60
Good		31+	0–24
Good[3]		31+	24+
Excellent[4]		31+	24+
Poor	31 or more	0–9	60+
Fair		0–9	0–60
Fair		10–20	0–60
Fair		21–30	0–60
Good		31+	0–60+

[1]Strothmann 1960.
[2]Percent of total cubic volume in upper 36 inches of soil.
[3]Subsoil pH 6.9 or less.
[4]Subsoil pH 7.0 or higher.

TABLE 7.—*Rating of topographic factors*

Topography rating	Slope[1]	Aspect[1]	Topographic position
	Percent		
Average	5–20	S and SW	Lower slope
Unfavorable			Upper and middle slope
		W, NW, N, NE, E, SE	Lower slope
			Upper and middle slope
Unfavorable	21 or	S and SW	Lower slope
Unfavorable	more		Upper and middle slope
		W, NW, N, NE, E, SE	Lower slope
			Upper and middle slope
Average	—	—	Depression
Unfavorable	—	—	Ridgetop

[1]Slope and aspect were assumed to have no influence on site quality on land having a slope of less than 5 percent (Strothmann 1960).

DESTRUCTIVE AGENTS

Quaking aspen stands may be damaged or destroyed by any of several agents. Insect infestations often reduce both volume growth and the value of timber. The average annual losses to Hypoxylon[7] in the Lake States are estimated to be 300 million cubic feet; this has a value of about $2 million on today's market (Marty 1972). Although fire is a useful tool in aspen management, it can also have adverse effects.

Insects

Of the many insects known to attack aspen, leaf feeders cause the most conspicuous damage. Stands may be completely denuded by the forest tent caterpillar and widespread injury sometimes is caused by the large aspen tortrix.

Forest Tent Caterpillar

The forest tent caterpillar is the most spectacular defoliator of aspen and of many other deciduous trees over large areas in the Lake States and adjacent Canada. Epidemic populations can develop in the same areas at 10- to 15-year intervals (fig. 8). Although they appear when the aspen leaves are beginning to unfold, the caterpillars are relatively inconspicuous until they are nearly full grown (Batzer and Morris 1971).

Enormous areas may be affected by the caterpillars. During the 1950's, one outbreak covered

F–307419

Figure 8.—Aspen trees completely defoliated by forest tent caterpillars.

[7]Common and scientific names of these and other aspen insects and diseases are listed in Appendix II.

about 80 million acres in Ontario (Sippell 1962). Most outbreaks last from 3 to 5 years; during this period, stands may be completely defoliated several times. High caterpillar populations may be abruptly reduced by low temperatures that kill both the newly hatched caterpillars and the leaves (Rose 1958, Hildahl and Reeks 1960). Populations eventually decline because of parasitism or of starvation in areas where the insects have exhausted the food supply (Christensen *et al.* 1951).

Although defoliated aspen stands commonly produce another crop of leaves 3 to 4 weeks after the caterpillar quits feeding, loss of the foliage reduces current growth (Dils and Day 1950, Batzer *et al.* 1954, Barter and Cameron 1955, Pollard 1972). Duncan and Hodson (1958) found that a typical outbreak (one light defoliation followed by 2 years of heavy defoliation) caused a volume loss of 0.6 cord per acre in average aspen stands, but as much as 2.25 cords per acre were lost in fully stocked stands growing on good sites.

Normally, few quaking aspen trees die following a typical infestation. The infestations in the 1930's coincided with a period of severe drought, however, and this resulted in heavy mortality, particularly of trees in the lower crown classes.

An outbreak can have beneficial effects. Where there are understory conifers, such as balsam fir, heavy defoliation of overtopping aspen results in a marked increase in radial growth of the conifers (Froelich *et al.* 1955, Duncan and Hodson 1958). And where the outbreak is accompanied by drought that kills part of the aspen overstory, many understory conifers are permanently released. Thus, an infestation can hasten natural conversion of aspen to conifers.

Widespread infestations of this insect cannot be economically controlled at the present time. However, defoliation of valuable aspen stands can be prevented by aerial applications of registered insecticides when the caterpillars are about ½-inch long.

Large Aspen Tortrix

The only other important aspen defoliator in the Lake States is the large aspen tortrix. This leaf roller periodically causes extensive defoliation of quaking aspen throughout much of its range (Adams and Moore 1963, Beckwith 1973). Prentice (1955) reported serious defoliation on 10,000 square miles in northern Manitoba and infestations have covered other large areas in the Lake States, Canada and Alaska. Outbreaks are characterized by the buildup of large populations that persist for 2 or 3 years and then suddenly collapse.

Feeding by the tortrix larvae is first noticeable in the spring. Where populations are high, aspen buds may be destroyed before they expand, but healthy trees usually produce more leaves by midsummer. Defoliation usually occurs in May or June when the larvae feed on leaves tied together by webbing (Beckwith 1973). Despite the loss in current volume growth caused by defoliation, most aspens survive. Although the larvae also will feed on a number of broadleafed species, the tortrix becomes a problem only where quaking aspen is a major component of the forest stand. Natural controls include feeding by birds and attacks by many species of parasites. Starvation stress apparently is a major factor responsible for population collapse of this species.

Poplar Borer

During their 3-year life cycle, larvae of the poplar borer make large tunnels in aspen trees. These tunnels ruin the wood for veneer and greatly reduce its value for lumber. Infested trees also are more susceptible to wind breakage.

Graham *et al.* (1963) reported that 64 percent of the quaking aspen trees growing in lower Michigan during the early 1960's showed evidence of being infested and that infested trees were equally abundant on all sites. However, Christensen *et al.* (1951) reported finding many more infested trees on poor sites than on good sites.

Most successful borer attacks are concentrated in individual trees or in small groups of trees scattered throughout stands. Among trees 2 to 7 inches d.b.h., Ewan (1960) found that "brood trees" were typically the larger and faster growing individuals and that the more open the stand the higher the amout of borer infestation. Although his data were inconclusive, trees larger than 7 inches are believed to be less susceptible to borer attack because their thicker bark interferes with egg laying.

No adequate control measures for the poplar borer are known. In Saskatchewan, the periodic removal of infested aspens proved worse than no control because opening of the stand was followed by an increase in new infestations (Peterson 1948).

Diseases

Quaking aspen in the Lake States is subject to a number of diseases. The more common ones attack the leaves and shoots, others cause cankers on the main trunk or larger branches, one causes a prominant roughening of the bark, and several initiate decay of the heartwood of the trunk or of the butt section and roots. However, Hypoxylon canker, shoot blights, and wood rots cause most of the economic damage.

Hypoxylon Canker

Hypoxylon canker, which is known to have been present since about 1920 (Povah 1924), is currently recognized as the most serious disease of quaking aspen in the Lake States. Bigtooth aspen is less frequently attacked (Graham *et al.* 1963), but many young quaking aspen stands are so heavily infected that their future productivity is questionable (Christensen *et al.* 1951, Anderson 1956). Graham *et al.* (1963) reported that 22 percent of all pole-sized and larger quaking aspen trees examined in lower Michigan had Hypoxylon cankers; they estimated that annual losses to the disease in this area alone amounted to 250,000 cords.

Cankers usually form only on young bark (Bier 1940), so older trees are attacked higher above the ground than young trees (Day and Strong 1959) (fig. 9). Trees seldom are killed by cankers on branches or on the trunk near the top of the crown (Christensen *et al.* 1951). However, most trees with bole cankers die because of girdling or stem weakening and subsequent wind breakage (fig. 10).

The amount of Hypoxylon canker present in an aspen stand is not directly related to site quality, vigor, or sex of the tree. The probability of infection is much greater on poor sites, however, because the slow-growing trees require so many years to reach merchantable size (Anderson 1953, Anderson 1958). Mortality in low-density stands is about twice that in well-stocked stands (Anderson 1956). There is some evidence that the disease is associated with wounds inflicted by the poplar and other wood borers (Graham and Harrison 1954); apparently the galleries of these insects provide infection courts.

No direct control measures are known for Hypoxylon disease. The soundest approach is to maintain well-stocked stands of aspen throughout the rotation (Anderson and Anderson 1968).

Decay

Decay-causing organisms are responsible for the greatest volume losses in aspen, and most of this damage is attributed to white heart rot. This fungus

F-516562
Figure 9.—Bole of aspen tree infected with Hypoxylon.

invades trees at dead branch stubs or at fire or borer scars (Schmitz and Jackson 1927, Christensen *et al.* 1951). Development of the fungus is rapid in older trees where the decay column may extend to the tree tops. However, decay most often terminates in the stump and seldom extends into the roots. Trees in which decay is in the advanced stages are easily broken by wind; most such trees show a number of conks or sporophores and are generally left by loggers even though they contain usable bolts.

Merchantable volume lost to decay increases with stand age—one study showed that the loss was 5 percent at 30 years, 8 percent at 45 years, but 20 percent at age 70 for aspen in northern Minnesota (Schmitz and Jackson 1927). In Ontario and Saskatchewan, cull caused by heartrot is not appreciable in aspen until the stands are about 90 years old (Riley 1952, Kirby *et al.* 1957, Morawski *et al.* 1958, Basham 1960).

F–516564

Figure 10.—Trees damaged by Hypoxylon canker are easily broken off by wind.

Shoot Blights

Young aspens may be damaged by shoot blights such as *Venturia tremulae* (Hepting 1971). This fungus develops on the leaves and may grow through the petioles into the stems. An infection occurring near the tip of a tree may kill the shoot which then withers and becomes bent. This "shepherd's crook" is common, especially in young stands. Many other stem and leaf diseases also are found on aspen (Appendix II), but they seldom affect extensive areas.

Mammals

Although quaking aspen is used for food by several species of mammals, they seldom cause appreciable damage except where overpopulations exist. Of the big game animals feeding on aspen, the white-tailed deer is the most important for it occurs throughout the aspen type in the Lake States whereas moose have a much more restricted range.

Most use of aspen by deer occurs during the first 3 to 5 years after a stand is cut. Deer browsing causes little lasting damage in most sprout stands because deer normally eat only the leaves, small twigs, and sprouts. Where other foods are scarce and deer populations are high, however, suckers may be browsed so heavily that serious losses of reproduction result (Graham 1958; Westell 1954, 1960). Such losses are less common in Minnesota than in lower Michigan (Westell 1956) and Wisconsin where deer are much more abundant. If the browsed suckers and twigs are more than ¼ inch in diameter, this indicates that there are too many deer and their food supply is inadequate in both quantity and quality (Graham *et al.* 1963).

Where severe browsing damage occurs, the deer population may be brought into better balance with food supply by a combination of one or more of the following: (1) killing-back overbrowsed sucker stands by burning, by disking, or by using herbicides to stimulate vigorous sprout regeneration; (2) making enough clearcuttings in merchantable aspen to provide an abundant supply of browse; and (3) permitting an increased harvest of deer (Graham *et al.* 1963).

Quaking aspen twigs and suckers are a preferred food of moose. In areas where there is a high population of moose, such as Isle Royale and parts of northeastern Minnesota, considerable damage to aspen reproduction has occurred (fig. 11) (Aldous and Krefting 1946, Krefting 1951). In 1971 Minnesota initiated a program of regulated hunting to control the moose population.

The young bark, twigs, and leaves of aspen are a favorite food of beavers. Stands within 300 feet (sometimes 650 feet) of a beaver lodge or dam may eventually be completely destroyed (Bradt 1947). Consequently, where beavers have been plentiful, there is usually little aspen near lakes and streams. After the larger aspen are consumed, the beavers move to other areas. Although beavers can cause considerable local loss of aspen, their impact on the resource is insignificant compared to that caused by decay and insect outbreaks.

The snowshoe hare (*Lepus americanus* Erxleben) and the cottontail rabbit (*Sylvilagus floridanus mearnsii*) (J. A. Allen) will girdle and kill aspen suckers extending above the snowline. Most root systems resucker; hence the damge involves only the loss of a few years' height growth (Graham *et al.* 1963). Mice and voles will girdle suckers underneath the snow. Damage from small animals is important only in years of peak populations; this is about every 10 years in the case of snowshoe hares.

Porcupines (*Erethizon dorsatum* L.) rarely cause extensive damage to aspen although Graham *et al.* (1963) reported that about 20,000 cords of merchantable material were destroyed on a 3,000-acre tract of aspen in lower Michigan. The animals

Figure 11.—Repeated heavy browsing by moose caused poor form on these aspen. (Photo by L. F. Krefting, USDI Bureau of Sport Fisheries and Wildlife.)

may consume the smooth outer bark of the upper trunk and branches during the winter months; if the exposed inner bark and cambium die, this sometimes kills a tree above the injured area. Where more preferred species, such as tamarack and sugar maple, are readily available, however, aspen consumption by porcupines is usually limited to twigs and buds during the spring.

Much of the aspen land in the Lake States is farmer-owned and some of this is grazed. Trampling by livestock compacts the soil, interfering with moisture absorption and root growth. Grazing, especially by sheep, destroys or damages any hardwood reproduction that may invade the stand. Where timber management is a major objective, grazing should be prevented; if grazing is of higher priority, the woodlot should be cleared for pasture.

Fire

Although fire is a useful tool in aspen management, it can also have adverse effects. Repeated burns can destroy all or most of the humus layer, causing reduced moisture absorption and retention. During the regeneration stage, a series of fires at 2- to 3-year intervals may completely destroy the suckering ability of the root systems (Buckman and Blankenship 1965). Although this suggests that controlled burns will reduce aspen suckers enough to favor reproduction of other species, too much time and effort are involved to make this technique practical (Horton and Hopkins 1965).

Saplings are killed to the ground by fires. The thin bark of large trees provides little protection for the cambium layer. The only visible damage after fires may be fire scars at the base of the tree, but these allow entry of borers and heart-rotting fungi. Both sapwood and heartwood of fire-killed trees are rapidly invaded by fungi and borers. By killing trees, fires reduce current stocking and volume and may affect the rate of growth in a stand. In older stands, however, fires seldom cause enough harm to the root systems to adversely affect suckering.

Climatic Factors

Quaking aspen stands may be damaged by wind, hail, ice storms, or unseasonable temperature extremes. High winds may uproot even sound trees and cause considerable breakage in those that are badly cankered. Such damage is much less frequent in young timber (Christensen *et al.* 1951, Forbes and Davidson 1962). Most heavy windstorms are local in effect, but some have affected a wide area in the Lake States (Stoeckeler and Arbogast 1955).

Severe hailstorms kill smaller trees and reduce the growth and vigor of large ones by breaking off twigs and small branches and scarring the larger branches and the trunks (Basham 1953, Riley 1953, Thomas 1956). Bruises from the hailstones likely serve as infection courts for Hypoxylon canker (Christensen *et al.* 1951). The trees may be so severely damaged that their crowns look one-sided and thin for many years (Riley 1953). Although they seldom affect extensive areas, one hailstorm covered an area of about 10 square miles (Basham 1953).

Ice or glaze storms, either alone or accompanied by sticky, wet snow, can cause heavy breakage of aspen crowns. Severe storms may essentially destroy entire stands (Christensen *et al.* 1951, Davidson and Newell 1956), but aspen is not as vulnerable to ice storms as the conifers (Cayford and Haig 1961).

Although frosts seldom cause serious damage to young aspen leaves, they will be killed when a period of unusually warm weather is followed by temperatures well below freezing. Such a situation occurred in 1953 over a wide area in Minnesota and adjoining Ontario and Manitoba—the death of the foliage was partly responsible for ending an outbreak of forest tent caterpillar (Rose 1958, Hildahl and Reeks 1960). Leaves killed by early frosts are replaced within a few weeks, so little actual loss of volume growth results.

Sunscald often follows heavy thinnings (Bickerstaff 1946), and some clones appear to be more susceptible to such injury than others (Graham *et al.* 1963). Scars from sunscald always occur on the south side of the trunks. Little direct damage usually results but the scars may provide access for heartrot diseases (Graham *et al.* 1963).

Severe drought will kill young seedlings and reduce the growth rate and vigor of sprouts and older stands, making them more vulnerable to attack by insects or disease (Christensen *et al.* 1951). This combination of factors can cause considerable mortality in older trees.

YIELD TABLES

The potential volume yields of aspen stands are limited by site quality because this factor strongly influences both height and diameter growth rates. The most recent forest surveys of the three Lake States show that about 11 percent of the aspen type is on poor sites (S.I. <50), 58 percent on average sites (S.I. 50 to 69), and 31 percent on good to excellent sites (S.I. ≥70).

Yield Tables for Unmanaged Stands

Kittredge and Gevorkiantz (1929) developed the first normal yield tables for aspen stands in Minnesota and western Wisconsin. Their tables showed that yields increased steadily up to age 80; the maximum was 80 cords per acre on excellent sites.

Experience showed that these tables overestimated the yields of unmanaged aspen stands so Gevorkiantz revised them (table 8) to allow for mortality and the decrease in growth rate with stand age (Zehngraff 1947). However, he was unable to allow for the increased proportion of cull trees in stands of advanced age. Most Lake States aspen stands are pathologically mature by age 60, after which cull trees may reduce merchantable volumes 60 percent or more (Zehngraff 1947).

The Gevorkiantz table shows that pure stands of quaking aspen on good sites will produce a maximum yield of 47 cords of pulpwood or 9,000 board feet of saw logs per acre at 50 years, the usual rotation age.[8] Medium sites produce their maximum yields at a rotation age of 45 to 50 years.

[8]In lower Michigan, bigtooth aspen produces one-third to two-thirds more volume than quaking aspen on land of the same quality (Graham *et al.* 1963).

TABLE 8.—*Gross yields per acre of aspen in unmanaged stands by age and site index*[1]

Age class	Site index					
	70	60	50	70	60	50
	Standard cords[2]			*Board feet (Scribner)*[3]		
20	8	—	—	—	—	—
25	19	7	—	—	—	—
30	29	16	5	1,300	300	—
35	36	24	13	4,000	1,400	—
40	42	30	17	7,000	3,000	1,100
45	46	32	18	8,500	5,000	2,400
50	47	33	16	9,000	6,000	3,000
55	46	30	13	9,100	6,000	2,900
60	43	26	10	9,000	5,800	2,500
65	37	20	6	8,400	5,200	1,800
70	29	14	4	7,400	4,500	1,400
75	21	9	—	6,000	3,200	700
80	12	4	—	4,200	1,500	—

[1] Prepared by S. R. Gevorkiantz, Lake States Forest Experiment Station (Zehngraff 1947).

[2] Gross volume of peeled wood in trees 4 inches d.b.h. and larger, to a minimum diameter of 3 inches inside bark.

[3] Gross volume of trees 7 inches in d.b.h. and larger, to a minimum of 6 inches inside bark.

Aspen on some relatively poor sites may produce up to 18 cords of pulpwood per acre (table 8); however, average yields of 11 cords per acre were reported for such sites in lower Michigan (Graham *et al.* 1963). Yields on poor sites are low because of slow growth rate, inadequate stocking, and greater loss from such diseases as Hypoxylon canker and various decays (Cox 1914, Zehngraff 1947, Anderson 1953, Basham 1958).

Yield Tables for Thinned Stands

Thinnings cannot improve the inherent capacity of a site to produce fiber. However, the volume utilized from trees thinned early in the rotation to reduce anticipated mortality will increase the total yield obtained from a stand. Such thinnings are usually made from below, so volume growth is concentrated on fewer and larger trees. Stand quality also is improved where poorly formed trees and unmerchantable species are removed.

Steneker and Jarvis (1966) predicted that total volume production of aspen stands in Manitoba and Saskatchewan might be increased about 25 percent from thinnings made at 5-year intervals if all-sized material could be utilized. However, they concluded that (1) returns from early thinning have little effect on total cordwood production because most trees removed are too small to be merchantable, and (2) operable thinnings usually would not be possible until age 30 to 40, when stand volume is between 15 and 30 cords per acre.

Because young aspens respond well to increased growing space, early thinnings enable trees to sustain rapid diameter growth rates, thus more trees reach veneer or saw log size in the normal rotation.

The effect of early thinnings on diameter growth rate was confirmed in long-term studies conducted in Minnesota. Aspen stands growing on a wide range of sites were thinned once to assigned stocking levels when the stands were from 10 to 30 years old. Periodic measurements made over the following quarter century provided data for even-aged stands ranging from 10 to 57 years in age and growing under a variety of stocking and site quality conditions.

Schlaegel (1971) used these data to develop equations for predicting stand volume in cubic feet based on combinations of site index, age, average diameter, and basal area stocking. With these equations, he prepared tables showing yields in cubic feet for stands with various average diameters and specific assumed utilization standards (Appendix III). He also used the basic data to prepare a table showing yields in cords per acre by stand age, basal area, and site index.

The height curves (fig. 12) Schlaegel used in preparing his tables are based on periodic height measurements of the same trees. As a result, they provide a more accurate estimate of height growth than the traditional curves which are based on single measurements of tree height and age. For the same site index, the Schlaegel curves show greater heights of dominant trees at 20 and 30 years than

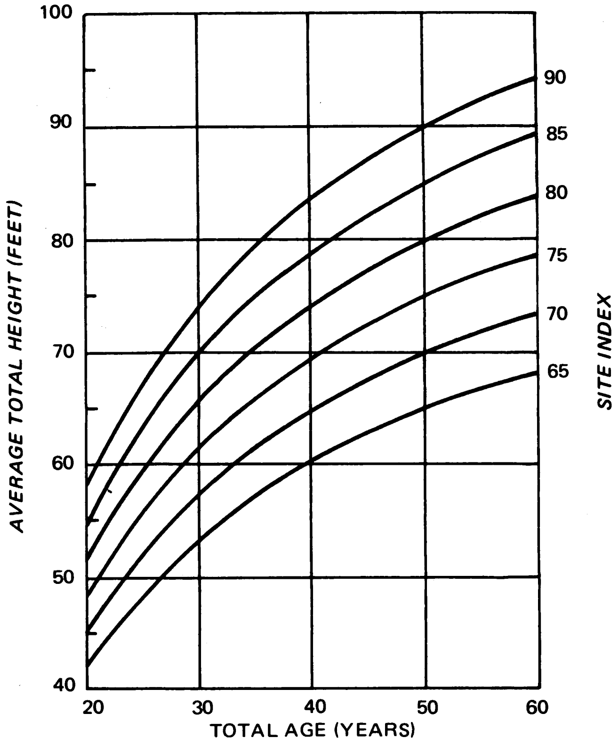


Figure 12.—Site index curves for quaking aspen in north-central Minnesota.

those shown in the curves prepared by Gevorkiantz (fig. 7) and Plonski (1956). Thus, Schlaegel's site index curves should be used with his yield tables, even though this might result in higher estimates of site index for young stands than indicated by the Gevorkiantz curves.

Schlaegel's tables show that predicted yields on all sites keep increasing through age 60 but at a decreasing rate. This indicates that some stands might be grown longer than 60 years, but any further increase in gross volume might be offset by losses in net volume because of decay, even on good sites.

Although they are based on measured stands that were located in a limited geographic area and on medium-textured soils, tests have indicated that these yield tables are applicable to pure aspen stands elsewhere in the Lake States (Schlaegel 1971). The cubic foot volumes associated with average tree size, site, and basal area in Schlaegel's tables generally agree with those reported by others (Plonski 1956, Kirby *et al.* 1957, Zehngraff 1947). Merchantable aspen yields for most natural stands will be less, of course, because other species are present and stocking will be less uniform. If these factors are considered in applying Schlaegel's yield tables, however, good volume estimates of the aspen component can be obtained.

HARVESTING

Aspen management in the Lake States at the present time typically consists of giving stands reasonable protection from fire and then cutting them when they reach merchantable size. Because aspen grows in even-aged stands, all sound trees 5 inches d.b.h. and larger customarily are harvested in one operation. Where markets permit, 4-inch trees also are taken. However, loggers seldom cut a tree that will not yield at least two pulpwood sticks, so most trees in the 4-inch class are left standing. Hardwoods and conifers that might be used for pulp also are often left because no local market is available.

Where special markets exist, the landowner may decide to harvest the large logs first and remove the other aspen in a later cut. If the landowner decides to use this two-cut approach in mature aspen, the first cut should remove no more than 40 percent of the merchantable saw log volume and 15 percent of the merchantable trees (Zehngraff 1947). Because cull percent usually increases rapidly after age 45, the final harvest cut should be made not more than 5 years later. Any further delay in making this final cut also increases the chance that tolerant conifers or hardwoods will replace aspen in the new stand or at least form a mixed type.

The adverse effects of past cutting practices on the quality of young aspen stands were evident in an inventory of the forest lands in Carlton, Cook, Lake, Pine, and St. Louis Counties of Minnesota (Office of Iron Range Resources and Rehabilitation and Lake States Forest Experiment Station 1964). Of the 240,000 acres of aspen less than 20 years old, only 27 percent had a stocking of 70 percent or more. An additional 12 percent of the stands were moderately stocked (40 to 70 percent) but seedbed or competition conditions indicated that a considerable investment would be required to make them fully productive.

Partial Cuttings

Overmature aspen stands often contain many defective, low-value trees. A commercial cutting may remove only the large sound trees for saw logs or veneer bolts and leave the small or poor-quality trees. Unless the residual trees are cut or killed, aspen suckers will be inadequate to form a well-stocked aspen stand. Instead, other species released by the partial cutting tend to take over the site.

Little is gained by partial cuttings from above, even when they are made in thrifty mature stands. An indication of what can happen following such partial cuttings was furnished by a study in a sawtimber stand on a good site on the Pike Bay Experimental Forest in Minnesota. Trees were removed to fixed diameter limits of 8, 9, and 10 inches at age 45 (fig. 13). During the 5 years following this cutting, the saw log volume added in these stands was the same or less than that in an adjacent uncut stand. Aspen regeneration suffered; the partially cut areas were invaded by brush or shade-tolerant hardwoods so the aspen suckers could not

F-313759

Figure 13.—Forty-five-year-old stand of aspen left after cutting from above to a 10-inch diameter limit.

develop properly because of the partial shade (Zehngraff 1947).

Mechanized Harvesting

Because well-stocked mature aspen stands contain a relatively high volume per acre in trees having a limited range of diameters, they provide excellent opportunities for mechanized harvesting. In addition, year-round harvesting is feasible on most aspen sites.

Mechanization of timber harvesting in the Lake States began in the early 1960's when rubber-tired skidders and self-loading trucks and trailers became available. The current trend is toward using more sophisticated machines such as timber harvesters, tree processors, feller-bunchers, and tree shears. For example, portable chippers are now available that can convert tree-length logs or full trees directly into chips for hauling to the mills in bulk carriers. Many of these machines are still in the developmental stage. As they become more efficient and versatile, their use is expected to increase.

Mechanization has increased productivity per man. A two- or three-man crew using chain saws and tree-length or full-tree skidding can produce up to 4,000 cords per year. Full mechanization could increase this to 7,000 cords per year.[9] The substantial investment in equipment is a strong incentive for year-round logging operations that provide stable jobs.

Machines are designed to handle a variety of jobs, so the woods operation may take several forms. Trees may be processed into shortwood in the woods, or they may be felled and limbed at the stump and hauled to mills in full merchantable lengths. In other operations, the trees are felled and forwarded to a nearby landing where they are limbed and either cut into pulpwood lengths or converted into chips.

Although the heavy machines used to fell and process trees cause varying degrees of site disturbance, little adverse effect on soils or watershed values has been observed (Zasada 1972). The greatest disturbance has resulted from full-tree skidding and summer logging. Full-tree skidding also has destroyed most of the brush. Aspen regeneration usually has been abundant except on main skid trails and at landings.

A major advantage of mechanized harvesting is that it can create conditions favorable for regenerating well-stocked stands of aspen. Slash can be concentrated where desired; brush can be uprooted and largely destroyed; and unmerchantable trees can be felled or broken off at low cost during the logging jobs. If properly used, mechanized harvesting systems thus can facilitate aspen management for sustained timber and wildlife production without causing serious damage to watershed or scenic values.

[9] Paper presented by Z. A. Zasada, University of Minnesota, at the joint meeting of the Great Lakes Deer Group and the Ruffed Grouse Workshop, Hill City, Minnesota, September 22, 1970.

ESTABLISHING VIGOROUS REPRODUCTION

Clearcutting is the best way to regenerate aspen stands because completeness of cutting largely determines the success of establishment and subsequent growth rate of new aspen forests. A complete clearcut removes all cull and nonmerchantable trees, some of which also are potential sources of Hypoxylon and rot infections.

An ideal way to achieve a complete clearcutting would be by utilizing all of the trees on an area. Improvements in efficiency of harvesting and processing equipment may soon make this practical. In 1972, field trials in southern Michigan showed that it was possible to cut all trees 2 inches d.b.h. and larger and convert them directly into chips that were usable by local industries. Although converting the chipped mixture of wood, bark, twigs, and leaves into fiber products usually requires modification of traditional techniques, these problems can be solved. If this harvesting system becomes economically feasible, it will encourage development of stands dominated by aspen.

As a rule, commercial cuttings in thrifty, well-stocked aspen stands remove or destroy nearly all the trees and a new aspen stand develops. Where commercial harvest cuttings are made in overmature stands or stands of mixed composition, however, many unmerchantable trees as well as small hardwoods and brush are left. This residual stand restricts the production and growth of aspen suckers (Stoeckeler and Macon 1956) (fig. 14). The results will be either an uneven, partially stocked stand of aspen and brush, a mixture of aspen and conifers or hardwoods, or an understocked stand

F-522788

Figure 14.—This commercial clearcutting left so many trees that aspen regeneration will be inadequate.

of thrifty aspen mixed with worthless culls. Although mixtures of aspen and conifers can be desirable, mixtures with other hardwoods may be considerably less productive. For example, most hardwoods associated with aspen in northern Minnesota consist of defective sugar maple, low-grade American elm and green ash, and slow-growing bur oak.

Eliminating Residual Trees and Brush

The requirement that residual trees must be cut or killed sometimes is included in timber sale contracts for National Forest and other public lands. Zasada and Tappeiner (1969) reported that mechanized full-tree harvesting can remove nearly all trees and brush. However, most commercial logging operations leave enough trees or brush to hinder successful establishment and growth of aspen suckers. Various methods can be used to control such unwanted vegetation.

Mechanical Equipment

Residual trees can be felled with chain saws. Brush can be controlled with brush choppers, KG blades, rock rakes, or other special machines capable of removing small- and medium-sized trees as well as brush. Costs are high but these heavy machines sometimes are used to regenerate aspen for wildlife habitat improvement.

Chemical Herbicides

Herbicides are useful tools in aspen management. They affect aspen and other woody plants in varying ways and degrees, depending on the chemical ingredients and when and how the herbicide is applied. Some herbicides kill aspen and other hardwoods without appreciable damage to conifers; others kill only the above-ground parts of aspen and result in prolific sucker development. A few herbicides are nonselective—they will damage or kill all vegetation.

Costs of chemicals vary considerably; some are relatively expensive. Where much unwanted vegetation must be controlled, however, this can be accomplished at lower cost with herbicide applications than with mechanical methods.

Some herbicides are suspected sources of environmental contamination. The potential hazards associated with such herbicides are being evaluated; some already have been approved for use under specified conditions. The forest manager should keep informed about current restrictions on herbicide use.

In aspen management, a primary use of herbicides has been to control culls, small trees, and brush that would prevent or restrict aspen sprout development on cutover areas. The kind and amount of the vegetation to be controlled usually determines what treatment is needed.

Where the brush is scattered and offers little competition, treatment of individual trees may suffice. Research has shown that most trees can be killed in any season with a solution of 2,4,5-T applied to fresh cuts in the bark,[10] or with undiluted 2,4-D amine applied with metering injectors. However, if individual aspen trees are treated during the peak of the growing season (June-August), the root systems may be killed, which would prevent later sucker production (Arend 1953, Worley *et al.* 1954).

Where the presence of many trees and heavy brush will restrict sucker initiation and development, aerial application of herbicides has been cheaper than individual tree treatment. To avoid killing the aspen root systems, too, Perala (1971) recommended delaying aerial spraying until early

[10] A 16 to 20 pound acid equivalent of 2,4,5-T ester formulation per 100 gallons of fuel or diesel oil has been effective.

August; although the existing aspen suckers would be killed, new ones would be produced the following year.

The above-ground parts of aspen trees have been killed by aerial application of 2½ to 3 pounds (acid equivalent) of a low volatile 2,4-D ester in 4 gallons of water emulsion per acre. In northern Minnesota, this treatment killed nearly all the 90-year-old aspen culls and controlled a dense underbrush of mountain maple and hazel so that excellent aspen suckering followed (fig. 15). Such species as red maple are resistant to 2, 4-D; where the residual stand contained many such trees, good control has been achieved by aerial applications of 1½ pounds each of 2,4-D and 2,4,5-T esters.

F-506116

Figure 15.—This dense stand of aspen developed where the overstory and brush were killed with herbicides.

Prescribed Burning

Where the operation can be handled without hazard to adjacent lands, research indicates that prescribed burning will set back the brush, kill unwanted trees, and get rid of some of the slash. Such burning is possible only when the aspen slash is dry enough to burn, however, and this may not be until the second spring or fall after logging. Any existing aspen suckers killed will resprout. Burning does not give lasting control of the brush, although enough stems may be killed to give the aspen suckers a chance to develop. Prescribed burning must be used with great caution and only by those who are thoroughly familiar with the behavior of fire. Actual costs may exceed those of chemical treatment because burning is possible only when the fire risk is high.

Increasing the Stocking of Sucker Stands

Because of past logging practices, many young stands are so poorly stocked with aspen or other merchantable species that future yields will be low. If growing aspen is his objective, the landowner may decide to let such stands grow until the aspen can be harvested and then make a clearcutting. An alternate solution is to eliminate the present stand by using herbicides or fire as previously described. This will encourage aspen sucker production and increase ultimate aspen yields.

Limited trials indicate that the number of aspen suckers in understocked stands also can be increased by disking. Where a Wisconsin area was disked in the fall, for example, 2 years later there were 5,500 to 7,800 suckers per acre compared with 1,200 stems on an undisked area. In the Upper Peninsula, Zillgitt (1951) found that disking increased stocking from 2,700 stems to 11,400 stems per acre within 1 year; on a somewhat poorer site, stocking was increased from 1,600 to 6,100 stems per acre by disking. These apparent benefits of disking are somewhat deceiving, however, because subsequent growth of the suckers was poor, and disking costs considerably more than other methods of site preparation to stimulate sucker production.

Logging During the Bark-Peeling Season

As recently as 1966, about half of the aspen pulpwood cut in the Lake States was sold after the bark had been peeled by hand. The bark-peeling season lasts from early May to early July. Where stands are cut after the end of May, however, the number of vigorous suckers produced may be inadequate to ensure regeneration of a new aspen stand. It is not always possible to schedule logging during May when the bark is easily peeled, so chemical debarking has been tried as a substitute for hand peeling. Applications of such chemicals as sodium arsenite and ammate, or the hormone herbicides 2,4-D and 2,4,5-T have been effective, but chemical debarking has never been widely used in the Lake States.

The problem of planning harvesting operations to coincide with the period of easy peeling is becoming less critical. Many pulpmills find it more efficient to practice year-round logging to reduce the area needed for cordwood storage and to prevent the loss in pulp brightness resulting from long storage of peeled wood (Auchter 1972). Other factors causing this change include the shortage of skilled loggers and the increasing use of mechanized harvesting and peeling.

MANAGEMENT ALTERNATIVES

In many respects, aspen is an ideal multipurpose tree. It can be managed at low cost to produce salable timber products while providing highly desirable wildlife habitat. Dependable regeneration from root suckers, intolerance causing early natural thinning and pruning, and fairly rapid volume growth over a short rotation make it possible to grow crops of aspen without treatments such as thinnings. In most instances the only direct investment involved will be provision for establishment and release of the aspen sprouts—treatment of residual trees and brush when the stands are harvested.

A higher level of management will increase timber crop values. For example, thinnings can increase the average size of trees at maturity, produce more veneer and sawtimber volume, and shorten the time needed to grow merchantable trees. Such thinnings may also increase total cubic volume yields over a rotation, but they also increase management costs.

Where continuous production of aspen is the management objective, some of these costs may be offset by other benefits of treatment. Increased yields per acre reduce costs per unit volume of harvesting and timber sale administration. In succeeding rotations, it will be easier to maintain aspen as the predominant species. Thus, the degree to which investments are expected to reduce the long-term costs of aspen management also should be considered by the forest manager.

Regardless of how aspen stands are managed, site quality limits potential growth rates and volume yields. Little can be done to increase the low aspen yields on poor sites. Medium-quality sites will produce trees of pulpwood size; practical treatment usually is limited to eliminating unmerchantable trees when stands are harvested to ensure vigorous aspen regeneration. Highest yields of both pulpwood and saw logs can be expected on the better sites where a much wider range of cultural treatments can be considered. Wide variations in site quality may occur within a limited area because of differences in aspect, topographic position, and soil characteristics. Extensive areas of uniformly good sites can be treated more efficiently than scattered small areas.

The distribution of the age or size classes must be considered by the aspen landowner in management planning. If the aspen land is fairly evenly divided into mature timber, pulpwood, poles, seedlings, and saplings stands, an orderly program of management could be readily installed. Where there are definite deficiencies in certain size classes, however, the best of management cannot prevent periods of lean returns. Such poor distribution can be corrected to some extent by adjusting the rotation length in the older age classes—shortening it in some stands or lengthening it in others. Of course, mature and overmature stands usually must be harvested as soon as possible to prevent further losses from decay.

Treatments to Increase Growth Rate

The abundant suckers produced after aspen stands are harvested ensure perpetuation of the type, but most of these suckers die long before they reach merchantable size. While they survive, however, these trees and those of unmerchantable species occupy growing space, use moisture and nutrients, and undoubtedly reduce the growth rate of the trees that live to form the merchantable crop.

If enough of these "excess" trees could be removed early in the rotation to provide adequate growing space for the potential crop trees, these would reach merchantable size in fewer years. Some trees would grow fast enough to produce saw logs, especially on the better sites. Such thinnings also could eliminate most trees of unmerchantable species, so the final stand would be dominated by aspen. Thus there is a good possibility that thinnings could increase net volume and value growth.

In deciding whether it would be profitable to thin aspen stands, the forest manager needs answers to several questions. What are the results of thinnings in stands of various ages? How early should thinnings be made to get maximum growth response? How many crop trees should be left? How long should thinnings be continued?

Research has shown that: (1) repeated thinnings before age 20 can accelerate diameter and volume growth of selected trees, reduce losses from natural mortality, and eliminate unwanted species; (2) thinning stands during the small pole stage (ages 20 to 30) provides enough growing space for selected trees so they will maintain maximum diameter growth rates; and (3) a single thinning should be considered in pole-sized stands between 30 and 35 years where a premium price is expected for large products and where the yield from the thinning itself will either show a profit or offset the costs.

These studies also show that both costs and risks must be considered in planning thinnings. Time is required to select the potential crop trees and to cut or deaden the others. The small trees cut in early thinnings usually would have little value, and thinnings in older stands may not yield enough merchantable volume to offset marketing and harvesting costs. Heavy thinnings increase the risk of losses to disease, windthrow, and sunscald. The thin bark of newly released aspen trees is subject to sunscald if large openings are created, so thinnings must leave enough trees to protect the boles of crop trees. A higher percentage of trees may become infected by Hypoxylon in heavily thinned stands (Anderson and Anderson 1968).

Although opportunities for profitable thinnings now are limited because of the low value of aspen, thinnings might become feasible if the market improves. The results of past studies provide valuable guidelines for such thinnings.

Thinnings in aspen sucker and sapling stands should improve stand quality and composition as well as give the residual trees more growing space. The largest trees should be reserved except when they are obviously diseased, deformed, or have other undesirable characteristics. Spacing of the trees left is of less importance than their quality. No slash disposal is necessary.

Herbicides cannot be used to thin aspen stands because of their interconnected root systems. Suckers and small saplings can be cut with machetes, bolo knives, or Phelps tools (fig. 16). Axes or small power saws, such as those used in brush clearing, are needed to cut larger trees.

F-476286

Figure 16.—Tools used to thin sapling stands. (The Phelps tool is on the right.)

In one study, an average of 11 man-hours per acre was required, using bolo knives and Phelps tools to cut aspen up to 3 inches in diameter and using axes to cut larger trees. An additional 3 man-hours per acre were needed to fell unwanted ash, oak, and elm, an operation that might be unnecessary where there is a potential market for such species.

No data are available on the time required to make thinnings in pole-sized and older stands of quaking aspen. However, Blair and Ralston (1953) reported that thinning 12-acre compartments in a 35-year-old stand of bigtooth aspen required 3.6 man-hours per cord for a heavy cutting from above (12 cords removed per acre), and 4.0 man-hours per cord for a heavy cutting from below (13 cords removed per acre). The 12-acre compartment that was clearcut required 3.0 man-hours per cord and yielded 22 cords per acre.

Thinnings in Sucker Stands

Because of the intense competition in typical dense sucker stands, relatively few trees attain diameters exceeding 2 inches in 8 to 10 years. In theory, at least, thinning such stands should sharply increase the growth rate of the remaining trees.

Graham *et al.* (1963) reported that 6,000 to 12,000 well distributed suckers per acre are more likely to develop into a better stand than 35,000 to 40,000. Results of a thinning study in a 1-year-old stand of aspen suckers in Minnesota indicated that even 6,000 stems per acre may be more than enough. Where stocking had been reduced from 10,000 to 1,000 stems per acre, Sorensen (1968) reported that basal area increased almost as much in 15 years as in an unthinned stand. Average tree diameter was 1 inch greater in the thinned stand, but the gain in average diameter for the 400 largest trees per acre was only 0.4 inch. After 20 years, the unthinned stand contained more volume per acre, although average tree diameters still were less than in the thinned stand.

Moreover, part of the increase in average diameter must be attributed to removal of small trees. Thus, the benefits were not adequate to justify the substantial costs. Sorensen (1968) concluded that areas stocked with from 1,000 to 10,000 1-year-old aspen stems per acre will produce an adequate number of potential crop trees, and that lack of thinning will have little effect on their diameter.

Thinnings in Sapling Stands

If thinning is postponed until the sapling stage, fewer trees will need to be cut and treatment still could shorten the time until cash returns can be obtained. This hypothesis has been under evaluation by the North Central Forest Experiment Station in a study begun 35 years ago in a 13-year-old stand and in a second study begun 20 years ago in an 11-year-old stand. Both stands are located on good sites in north-central Minnesota.

In the first study, five degrees of thinning were tested on 0.6-acre plots having from 3,500 to 4,900 stems per acre (fig. 17). After treatment, there were from 400 to 1,700 stems per acre on the thinned plots compared with 3,600 stems per acre on the check plot. None of the trees left was more than 3 inches in diameter; tree heights ranged from 23 to 27 feet (fig. 18).

After 5 years, volumes ranged from 1 to 5 cords per acre. In 10 years, this had increased to 11.2 cords on the check plot as compared to 11.1 cords on the plot thinned to 540 trees (fig. 19) and to 10.4 cords on the plot where 980 trees were left. The other thinning treatments reduced volume growth considerably. At this time (stand age 23 years) an additional thinning was made in all but the check plot. Actual pulpwood yields from this thinning ranged from 1.7 to 1.9 cords per acre.

F-392287

Figure 17.—Competition is intense in dense aspen sapling stands such as this; thinning would remove most of the trees that would die normally and concentrate volume growth on the residual trees, Chippewa National Forest, Minnesota.

F-326058

Figure 18.—Thirteen-year-old aspen sapling stand just after thinning to 540 trees per acre, Chippewa National Forest, Minnesota.

F-439564

Figure 19.—Pulpwood volume is 11.1 cords per acre in this stand 10 years after it was thinned at age 13 to leave 540 trees per acre, Chippewa National Forest, Minnesota.

Subsequent growth continued to be rapid, so additional cuttings for pulpwood were made from below on all but the lightest thinned plots at age 28 and on all the thinned plots at age 33.

After 35 years (stand age 48), the unthinned plot contained the least aspen volume; total volume was highest but 29 percent of this was in low-value hardwoods (table 9). Early thinning and control of these other hardwoods in the other plots resulted in more total aspen production than in the unthinned plot.

Thinning also increased the number of large trees containing potential saw logs or veneer bolts. Although the plot thinned to leave about 400 trees per acre contained more trees 14 inches d.b.h. and larger, overall volume and quality production were better on plots where more trees were left.

Early results of the small-scale study were encouraging, so a 20-acre area was thinned in an 11-year-old stand to see if leaving about 750 trees per acre would be a practicable level to use in aspen saplings. Other tree species were eliminated from the thinned stand. An untreated portion of the stand was used as a check.

After 20 years, the thinned and unthinned stands contained about the same number of trees per acre, but distinct differences in diameter distribution were evident at stand age 31 years. There were nearly twice as many aspens 7.6 inches d.b.h. and larger (95 versus 53 per acre) in the thinned stand, and many of these can be expected to produce saw logs or veneer bolts at maturity. The thinned stand also contained 6 cords more aspen volume per acre.

However, this thinning had some adverse effects. In the first 15 years after thinning, 23.6 percent of the aspens were killed by Hypoxylon in the thinned stand compared with 14.4 percent in the unthinned stand (Anderson and Anderson 1968). This reduced stocking in the thinned stand below the optimum for maximum volume production. Of

TABLE 9.—*Aspen volume production per acre in stands on good sites given noncommercial thinnings to various densities at age 13 (Pike Bay Experimental Forest, Minnesota)*

Data	Trees left per acre in first thinning					
	3,630 (check)	1,700	1,210	980	540	400
	Cubic feet[1]					
Stand at age 48	[2]3,058	3,673	3,162	3,612	3,385	3,150
Harvested in thinnings	—	224	504	1,017	868	551
Total production	3,058	3,897	3,666	4,629	4,253	3,701
	Cords[3]					
Stand at age 48	38.7	46.5	40.0	45.7	42.8	39.9
Harvested in thinnings	—	2.8	6.4	12.9	11.0	7.0
Total Production	38.7	49.3	46.4	58.6	53.8	46.9

[1]Merchantable cubic volume inside bark to a 3-inch top (d.i.b.) of trees 3.6 inches d.b.h. and larger.
[2]The check plot also contained other hardwoods; these had a volume of 1,118 cubic feet (14.1 cords).
[3]Based on 79 cubic feet per rough cord.

all trees that died in the thinned stand, more than two-thirds were killed by Hypoxylon, which emphasizes the susceptibility of high-vigor trees to this canker. To reduce the risks of Hypoxylon infection, the authors suggested that aspen stands should be maintained at or near full stocking to assure the greatest fiber yield even though the growth rate of individual trees will be adversely affected.

In Manitoba, Steneker (1964) evaluated the effects of early noncommercial thinnings in well-stocked aspen stands 14, 19, and 23 years old on good sites. Each stand was thinned to leave trees spaced 12 by 12, 10 by 10, and 8 by 8 feet apart. Thinning to an 8 by 8 spacing resulted in production of more large trees in 10 years than either of the wider spacings or the control, and more pulp volume than where fewer trees were left.

Thinnings in Pole-Sized Stands

The effectiveness of crop tree thinning was tested in 20-year-old stands on good site (S.I. 70+) on the Chippewa National Forest, Minnesota. Selected trees were released by cutting competing trees of the same crown class; intermediate and suppressed trees were left. Treatments compared growth in an uncut stand with that where crop trees were spaced about 10, 15, and 20 feet apart. The stands were given no further treatment until they were harvested 30 years later at age 50.

After 30 years, pulpwood volumes of both aspen crop trees and of all trees were highest in the unthinned stand and where crop trees were spaced about 10 feet apart (table 10). In the thinned stands, yields of aspen saw logs were from 500 to 800 board feet per acre more than in the unthinned stand. Average tree diameter was directly related to thinning intensity, ranging from 7.8 inches in the unthinned stand to 11.6 inches where crop trees were spaced 20 feet apart. Many of these larger trees were quite limby, however, and produced only one clear log. Thus, the net effect of these noncommercial thinnings at age 20 in stands growing on good sites was the production of fewer but larger trees containing more saw log but less pulpwood volume.

On excellent sites, however, thinnings in young stands can greatly increase volume growth rate. For example, where 460 trees per acre were released in a 25-year-old stand (S.I. 90), average annual growth rate per acre during the next 20 years was 1.69 cords compared with 1.25 cords in an adjacent unthinned stand.[11] Although a pulpwood thinning at age 39 removed 13.4 cords per acre from the thinned stand, total aspen volumes at age 45 were about equal in both stands—from 39 to 40 cords per acre. At age 45, average tree diameter was 10.0 inches in the thinned stand compared with 7.6 inches in the unthinned stand. These results suggest that a noncommercial thinning on excellent sites can speed up diameter growth enough to make a commercial thinning feasible.

First Thinning at Age 30 or Later

Only the best sites (S.I. 70+) produce enough volume at age 30 to 35 years to support a profitable thinning, so the opportunities are limited. The operation should yield 10 or more cords per acre and still leave a good stand (60 to 80 square feet basal area) of thrifty dominant or codominant trees.

[11] Unpublished results of a study by John W. Hubbard, on file at Boise-Cascade Corporation, International Falls, Minnesota.

TABLE 10.—*Stand basal area and volume per acre 30 years after a crop tree thinning in aspen stands at age 20, Chippewa National Forest, Minnesota*

Treatment—crop tree spacing	Aspen crop trees			All trees[1]		
	Basal area	Volume: Pulpwood	Volume: Saw log	Basal area	Volume: Pulpwood	Volume: Saw log
	Ft²	*Cords*[2]	*Fbm*[3]	*Ft²*	*Cords*[2]	*Fbm*[3]
Not thinned	100	37.4	5,530	109	39.7	5,930
10 by 10	100	36.8	6,390	106	39.1	6,470
15 by 15	74	26.2	6,290	97	35.0	6,420
20 by 20	80	19.7	6,370	87	31.4	6,660

[1] All crop trees plus ingrowth of all species during the 30 years.
[2] Volume in rough cords of trees 3.6 inches d.b.h. and larger to a 3-inch top d.i.b.
[3] Board-foot volume (International ¼-inch rule) of trees 7.6 inches d.b.h. and larger to a 6-inch top d.i.b.

QUAKING ASPEN

A study on the Chippewa National Forest compared the growth and yield of 30-year-old stands on good sites after the following treatments: (1) a moderate thinning from below leaving about 275 trees per acre; (2) a heavy thinning from below leaving 150 trees per acre; and (3) a moderate thinning from above. The thinnings removed from 7.7 to 17.6 cords per acre (table 11). Volume production in the thinned stands was compared with that in an adjacent uncut stand.

After 27 years, the uncut stand and the stand that was thinned moderately from below contained more cordwood and saw log volumes than either of the other thinned stands. However, total cordwood production was 27 percent higher, and actual growth during the 27-year period was 24 percent higher in the stand thinned moderately from below (fig. 20) than in the uncut stand. Saw log volumes were considerably less in stands thinned from above or heavily thinned from below.

In another study made on an excellent site, thinnings in 32-year-old, well-stocked aspen stands yielded an average of 27.9 cords and left 29.5 cords per acre (Hubbard 1972). After 17 years (stand age 49), volume had increased to 52.8 cords per acre. Total volume production was 80.7 cords per acre in the thinned stands, as compared to 63.6 cords per acre in an adjacent unthinned stand of the same age. Mean annual volume production per acre was 1.65 cords in the thinned stands where the average tree diameter was 11 inches; corresponding values for the unthinned stand were 1.30 cords and 9.3 inches.

In contrast, Schlaegel and Ringold (1971) reported that a single thinning in a 37-year-old aspen stand did not increase either total volume production or the number of veneer-sized trees after 10 years. Response to thinnings apparently decreases as stands near rotation age, but the critical age probably varies among aspen clones.

F-328304

Figure 20.—Moderate cuttings from below in quaking aspen of medium age such as this 30-year-old stand on the Chippewa National Forest, increase the size of the final crop trees as well as total yield.

Few studies have been made of thinnings in older stands on medium or poor sites. Pike (1953) reported a small increase in yield during the 20-year period following light and medium thinnings from below in a 35-year-old stand on a medium site

TABLE 11.—*Effect on volume growth of aspen stands of single thinnings at age 30 to different stocking levels, Chippewa National Forest, Minn.*

Treatment	Volume age 30			Volume age 57		Total production	Growth in 27 years
	Total	Cut	Left	To 3 in. top	Saw logs		
	Cords [1]	*Cords* [1]	*Cords* [1]	*Cords* [1]	*Fbm* [2]	*Cords* [3]	*Cords*
Moderate thinning from below	26.6	14.2	12.4	47.2	15,370	61.4	34.8
Heavy thinning from below	24.6	17.6	7.0	29.1	10,750	46.7	22.1
Moderate thinning from above	21.1	7.7	13.4	43.3	11,960	51.0	29.9
Unthinned	20.4	—	20.4	48.4	14,200	48.4	28.0

[1] Volume per acre in rough cords of trees 3.6 inches and larger to a 3-inch top d.i.b.
[2] Board-foot volume per acre (International ¼-inch rule) of trees 7.6 inches and larger to a 6-inch top.
[3] Sum of original cut plus stand volume at age 57.

in Manitoba. On the basis of the growth made during a 10-year period on plots thinned at 17 and 40 years on medium sites and growth after a thinning at 22 years on a good site, Bickerstaff (1946) concluded that thinning of aspen is not practical except on the best sites.

Improving Genetic Quality of Aspen Stands

Quaking aspen clones vary greatly in growth rate and bole form, so it should be possible to increase stand productivity by upgrading average genetic quality. Garrett and Zahner (1964) tested several treatments designed to favor sucker production of selected bigtooth aspen clones in Michigan. They reported wide variation in suckering ability among clones, and concluded that drastic treatments would be required to ensure adequate propagation of some desired clones. A possible solution would be: (1) cut all trees of the less desirable clones and kill their root systems to prevent suckering; and (2) cut trees of the selected clones a year later so their sprout regeneration would dominate the new stand.

A more reliable way to improve the genetic quality of aspen stands would be to plant hybrids or selected clones that show superiority in growth rate and in resistance to insects and diseases, and that will also produce high-quality wood and fiber. Research has shown that trees having many of these desirable characteristics can be produced; the major remaining problem is development of satisfactory regeneration techniques. After such improved aspens become available in sufficient quantities, they could be planted on the best available sites where intensive culture could be used to maximize volume and value yields.

OTHER MANAGEMENT ALTERNATIVES

Quaking aspen in the Lake States often grows in stands that include varying proportions of paper birch, northern hardwoods (sugar maple, yellow birch, American basswood, and northern red oak), or conifers (pines, spruces, balsam fir, and northern white-cedar). In some stands, these other species occur as scattered trees or groups of trees that are codominant with the aspen. In other stands, the more tolerant conifers or hardwoods may form a dense understory. Variations among species in tolerance and rotation age often make it difficult to manage mixed stands for maximum volume and value yields. Available markets may make it more profitable to discriminate against aspen on sites where other species can produce wood of higher value.

Aspen with Complete Understory

Conversion is easily accomplished where the associated species form a more or less complete understory (fig. 21). If the aspen is of merchantable size, it can be harvested to release the overtopped trees. Early release is especially beneficial to balsam fir because frequency of decay is highest among suppressed trees and response to release seems to be more dependent on absence of decay than on age. Conversion to other species seldom will be completed in a single rotation regardless of the harvesting method used. Harvesting only merchantable trees will be more economical than complete clearcutting, and the partial shade of residual trees will inhibit aspen suckers. Moreover, at least some of the aspen trees left may grow large enough to furnish an additional yield when the next harvest cut is made (Cooley and Lord 1958).

Mixtures of Aspen and Other Species

In many mixed stands, the species growing with aspen make up a relatively small proportion of total stocking. Unless intensive measures are used to eliminate the present stand and plant or seed some preferred species, changing stand composition will be a gradual process requiring several rotations.

The simplest approach is to use measures favoring the more tolerant species—harvest the aspens as they mature without any attempt to cut cull trees or control brush and reproduction. This will restrict development of the aspen suckers, and other species will eventually replace the aspen. This harvesting practice has been responsible for most natural conversion in the past, so the results can be predicted.

Rate of conversion and composition of the new stands are largely uncontrolled, but periodic yields of aspen and other species are possible. Harvest cuttings of shade-tolerant trees made in the winter or spring following good seed crops will favor their regeneration. If conditions warrant it, some type of seedbed preparation could be made in advance of seed fall.

F-460880

Figure 21.—Well-stocked, near mature aspen stand with a fairly dense understory of thrifty balsam fir. Aspen is 36 years old and on good site, Nicolet National Forest, Wisconsin.

Where mixed stands are to be converted to easily wind-damaged species, such as balsam fir and spruces, excessive windthrow may result if the stands are opened up too much in one cutting. This occurred in a Minnesota stand composed of mature aspen mixed with uneven-aged balsam fir and considerable low-grade sugar maple, ash, and elm. The objective was to convert the stand to balsam fir. After all merchantable aspen and high-risk balsam firs were harvested, the cull aspens and larger hardwoods were killed with herbicide and the smaller hardwoods were cut with a power saw. This postlogging cleanup was a mistake—it opened up the stand so much that practically all of the thrifty balsam fir blew down. The aspens suckered so abundantly that the new stand consisted almost entirely of aspen instead of a balsam fir stand containing a few aspen.

Aspen and Balsam Fir as Alternate Crops

On some sites, aspen and balsam fir are the most abundant species, and they could be grown as alternate crops. Both species grow rapidly and are quite short-lived. They can be handled on rotations of about the same length. Balsam fir is tolerant and will become established under aspen, whereas aspen suckers outgrow balsam fir seedlings and soon become dominant. All that is needed to begin such alternation is either one of the following situations: (1) a near mature stand of aspen with a good understory of balsam fir, or (2) a mature stand of fir containing a scattering of aspen trees.

Clearcutting a mature aspen stand will release a balsam fir understory, which will reach merchantable size in another 30 or 40 years because of its rapid growth. Most understory balsam stands have openings that will be invaded by the aspen suckers. As a result, when the balsam fir stand matures, it will contain some aspens, as in the second situation described above. If both aspen and balsam fir are cut at the same time, a sucker stand will be obtained that rapidly overtops the small balsam fir seedlings common under most balsam fir stands.

Converting Aspen Lands to Pine or Spruce

Lands capable of growing aspen usually are suitable for pine or spruce. Land managers may prefer to grow these species for wood products or to provide a more diversified forest cover, but natural conversion of aspen or other hardwood types to conifers other than balsam fir seldom occurs. Thus, special efforts are necessary to establish satisfactory stands of pine or spruce.

Competing vegetation must be controlled by cutting or other mechanical methods, by use of registered herbicides, or with a combination of these methods. Trees usually must be planted, although direct seeding may be effective in special cases. Subsequent release of the established conifers usually is required to ensure their proper development.

Detailed descriptions of the steps necessary to establish conifers are available in the various planting and seeding handbooks. Chances of successful establishment are improved by careful site selection and preparation, by planting good growing stock of suitable species, and by providing adequate subsequent release. The high costs undoubtedly will limit conversions of aspen lands to pine or spruce.

GUIDELINES FOR ASPEN MANAGEMENT

In the Lake States and adjacent Canada, research and experience have shown that the key to successful aspen management is harvesting by clearcutting to ensure vigorous sucker production and development. Aspen grows faster, reaches larger size, and produces higher yields on good than on poor sites. Thus, where premium prices are expected, a thinning may be justified on good sites to increase yields of saw logs and veneer bolts. Although intensive culture will further increase volume yields, actual financial gains are limited by the relatively low present value of aspen.

In most cases, harvesting only the merchantable trees will not create the conditions needed for adequate sprout regeneration. Both the number and vigor of suckers can be increased if residual trees and brush are controlled by cutting, burning, or use of registered herbicides. In general, the better the site, the greater the need for and benefits derived from such treatments. Minimum sucker stocking needed is 3,000 to 6,000 vigorous stems per acre if these are well distributed and free to grow.

Where successive aspen crops are planned, the final harvest cutting should be made at or near the suggested rotation age. If harvest is delayed more than 10 years, there is risk of appreciable losses in yield and quality. Harvest cuttings made in the dormant season result in the most abundant sucker development, but adequate stocking can be expected regardless of when an aspen stand is clearcut.

The following guidelines are suggested for managing aspen stands on sites of three broad quality classes.

Good and Excellent Sites (S.I. 70 or Higher)

On these better sites aspen grows faster, produces larger, higher quality products, and is most responsive to treatment. Because maintaining pure stands of aspen on such sites also provides highly desirable habitat for deer, grouse, and other wildlife, growing repeated crops of aspen justifies the special efforts required to prevent natural conversion to other species. The first and most crucial requirement is that a clearcutting must be made—all culls and unwanted tree species must be cut or killed and excess brush must be controlled. This will encourage vigorous aspen suckering and ensure good stocking. Plan for a rotation of 50 to 60 years.

Maximum production of large, high-value products will be achieved where the stands are thinned from below at least once during the rotation. In well-stocked stands, an operable thinning often can be made at age 30 to 35 to leave 60 to 80 square feet basal area. Earlier thinnings will increase growth rates and ultimate size of the potential crop trees even more. As markets improve for high-quality aspen logs, thinnings are expected to become more profitable on good aspen sites.

Average Sites (S.I. 50 to 69)

Because most aspen stands of the Lake States are growing on sites within this broad range, maintaining good production rates on these sites is essential to ensure adequate supplies of aspen for industry and to maintain desirable wildlife habitat.

Potential yields are high enough to justify favoring aspen, especially where site index exceeds 60. The major goal is production of pulpwood on a 40- to 50-year rotation, but some trees will produce veneer bolts and saw logs. Mature stands usually will be commercially clearcut; the loggers should be encouraged to break off or uproot as many unmerchantable trees as possible.

Aspen regeneration and future yields will be further increased by a complete clearcutting and control of excess brush. This is recommended where existing or expected markets favor maximum aspen production. However, where markets are poor, the forest manager may decide to leave scattered trees and brush. Noncommercial thinnings are not recommended, but a single commercial thinning at age 30 to 35 should be considered where premium prices are expected for large logs.

Poor Sites (S.I. Less than 50)

Managing aspen primarily for wood production is impractical on poor sites because of low yields and quality. When stands mature at 30 to 35 years, they may be harvested if an operable cut can be made. No investment can be justified to ensure aspen regeneration. It may be desirable to convert some poor aspen sites to jack pine, red pine, or spruce, but choice of species often is limited.

Inherent low productivity limits the potential value of poor aspen sites for deer and grouse habitat. However, where more suitable sites are not available, a combination of prescribed burning and aspen harvest cuttings will stimulate production of desirable food and cover for wildlife.

SUMMARY

Aspen forms the largest and most widely distributed forest type in the Lake States where it occupies about one-fourth of the commercial forest land. There are over 13 million acres of aspen forest in Minnesota, Wisconsin, and Michigan. The dominant species, quaking aspen, may grow in essentially pure stands but varying numbers of other species usually are present. Common associates in the Lake States include paper birch, balsam fir, jack pine, spruces, northern red oak, elms, big tooth aspen, red pine, or white pine.

Over its wide range, aspen occurs on a variety of soils and sites. Growth rate varies with soil fertility and moisture. Tree heights at age 50 range from 90 feet on deep fertile loams to 40 feet on dry sands, rock outcrops, water-logged mineral soils, or peat. About 11 percent of the aspen type occurs on poor sites (S.I. <50), 58 percent on average sites (S.I. 50 to 69), and 31 percent on good to excellent sites (S.I. ≥ 70).

Most Lake States aspen stands are young. About 70 percent are less than 40 years old and only 4 percent are distinctly overaged. Over half the stands are pole-sized; a third are seedlings or saplings. Only 6 percent of the type is owned by industry; the rest is nearly evenly divided between public and small private ownerships.

Aspen is one of the simplest species to manage because it is easy to regenerate from root suckers, and its intolerance causes early natural thinning and pruning. Even without thinnings, aspen stands on average and better sites produce cordwood along with some larger products in a short rotation. The only direct investment usually needed is treatment of residual trees and brush at the time of harvest to stimulate production and rapid growth of aspen suckers.

The recommended practice is to make either a complete clearcut or a commercial harvest followed by cutting or killing the remaining overstory. The brush that is often present on the better sites may be controlled using prescribed burns, but application of approved herbicides is more reliable. Mechanical treatments also are effective although costs will be higher. Favorable growing conditions must be provided for aspen sucker development.

Volume growth rate and yields are related to both site quality and aspen stocking. Average aspen yields in unmanaged mixed stands often are only 10 to 15 cords per acre. Pure, well-stocked aspen stands on excellent sites yield 60 or more cords per acre, but poor sites may not produce enough volume to be worth harvesting. On the better sites, a single commercial thinning from below should be considered at age 30 to 35 years, especially where large, high-quality trees will bring premium prices in the final harvest.

Periodic defoliation of aspen stands by the forest tent caterpillar or other leaf feeders may reduce volume growth during infestations. Trees of any age can be attacked by the aspen borer, but infestation is most frequent in poorly stocked or thinned stands. Hypoxylon canker is the most serious disease, resulting in death or breakage of many trees; infection may be reduced by maintaining well-stocked stands. Because losses to decay fungi increase rapidly in overmature stands, aspen harvest should not be unduly delayed.

To minimize losses to insects and diseases, aspen should be grown in well-stocked stands and harvested promptly at maturity. Recommended rotations for aspen stands range from about 30 years on poor sites to 50 or 60 years on good sites.

Growing continuous crops of aspen also plays a key role in maintaining other natural resources. Aspen suckers are a staple food of moose and deer. The staminate flower buds of aspen trees are a necessary winter food for grouse and stands of all ages provide favorable habitat for grouse and other birds. Aspen bark and twigs are the primary food of beaver. The easily regenerated aspen provides soil cover that helps stabilize the water regime, and aspen forests have considerable esthetic and recreation value.

LITERATURE CITED

Adams, S. D., and L. H. Moore.
1963. Lake and Central States. *In* Forest insect conditions in the United States, 1962. USDA For. Serv., 30 p.

Aldous, Shaler E., and Laurits W. Krefting.
1946. The present status of moose in Isle Royale. North Am. Wildl. Conf. Trans. 11: 296–308, illus.

Aldous, Shaler E., and Clarence F. Smith.
1939. Fall and winter food habits of deer in northeastern Minnesota. U.S. Bur. Biol. Surv., Wildl. Res. and Manage. Leafl. BS 137: 10 p.

Anderson, Gerald W.
1958. Hypoxylon infection not greatly influenced by sex of aspen trees. USDA For. Serv., Lake States For. Exp. Stn. Tech. Note 535: 1 p. Lake States For. Exp. Stn., St. Paul, Minn.

Anderson, Gerald W., and Ralph L. Anderson.
1968. Relationship between density of quaking aspen and incidence of Hypoxylon canker. For. Sci. 14: 107–112, illus.

Anderson, Ralph L.
1953. Hypoxylon canker of aspen in the Lake States. USDA For. Serv., Lake States For. Exp. Stn. Tech. Note 400: 1 p. Lake States For. Exp. Stn., St. Paul, Minn.

Anderson, Ralph L.
1956. Hypoxylon canker of aspen. USDA For. Serv., For. Pest Leafl. 6: 3 p., illus.

Arend, John L.
1953. Scrub aspen control with basal sprays. USDA For. Serv., Lake States For. Exp. Stn. Tech. Note 401: 1 p. Lake States For. Exp. Stn., St. Paul, Minn.

Auchter, Richard J.
1972. Trends and prospects for aspen use in fiber products. *In* Aspen: symposium proceedings. USDA For. Serv. Gen. Tech. Rep. NC-1: 154 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Ayres, H. B.
1900. Timber conditions of the pine region of Minnesota. U.S. Geol. Surv. Annu. Rep. 21 (1899–1900), Part V, For. Reserves: 673–689.

Baker, Frederick S.
1921. Two races of aspen. J. For. 19: 412–413.

Baker, Frederick S.
1949. A revised tolerance table. J. For. 27: 179–181.

Baker, Whiteford L.
1972. Eastern forest insects. U.S. Dep. Agric., Agric. Handb. 1175: 642 p.

Barnes, Burton Verne.
1959. Natural variation and clonal development of *Populus tremuloides* and *P. grandidentata* in northern lower Michigan. Diss. Abstr. 20: 1511–1512.

Barnes, Burton Verne.
1961. Hybrid aspens in the Lower Peninsula of Michigan. Rhodora 63: 311–324.

Barnes, Burton Verne.
1966. The clonal growth habit of American aspens. Ecology 47: 439–447.

Barter, G. W., and D. G. Cameron.
1955. Some effects of defoliation by the forest tent caterpillar. Can. Dep. Agric., For. Biol. Div. Bimon. Prog. Rep. 11(6): 1.

Basham, J. T.
1953. Extensive tree mortality caused by hail in Quetico Provincial Park. Can. Dep. Agric., For. Biol. Div. Bimon. Prog. Rep. 9(5): 2.

Basham, J. T.
1958. Decay of trembling aspen. Can. J. Bot. 36: 491–505, illus.

Basham, J. T.
1960. Studies in forest pathology XXI. The effects of decay on the production of trembling aspen pulpwood in the Upper Pic region of Ontario. Can. Dep. Agric. For. Biol. Div. Publ. 1060: 25 p., illus.

Batzer, H. O., A. C. Hodson, and A. E. Schneider.
1954. Preliminary results of an inquiry into effects of defoliation on aspen trees by the forest tent caterpillar. Univ. Minn. For. Note 31: 2 p.

Batzer, H. O., and Robert C. Morris.
1971. Forest tent caterpillar. USDA For. Serv., For. Pest Leafl. 9: 5 p., illus.

Beckwith, Roy C.
1973. The large aspen tortrix. USDA For. Serv., For. Pest Leafl. 139: 5 p.

Bickerstaff, A.
1946. The effect of thinning upon the growth and yield of young aspen stands. Can. Dep. Mines and Resour., Lands, Parks and For. Branch, Com. For. Serv. Silvic. Res. Note 80: 25 p., illus.

Bier, J. E.
1940. Studies in forest pathology III. Hypoxylon canker of poplar. Can. Dep. Agric. Tech. Bull. 27: 40 p., illus.

Blair, Rowland W., and Robert A. Ralston.
1953. Comparison of man-hours required for thinning pole-size aspen. USDA For. Serv., Lake States For. Exp. Stn. Tech. Note 407: 1 p. Lake States For. Exp. Stn., St. Paul, Minn.

Blyth, James E.
1970. Pulpwood production in the North Central Region by county, 1969. USDA For. Serv. Resour. Bull. NC-11: 23 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Boyce, John Shaw.
1961. Forest pathology. Ed. 3: 572 p., illus. New York: McGraw-Hill.

Bradt, G. W.
1947. Michigan beaver management. Mich. Dep. Conserv. 56 p., illus.

QUAKING ASPEN

Buckman, Robert E., and Lytle H. Blankenship.
1965. Repeated spring prescribed burning reduces abundance and vigor of aspen root suckering. J. For. 63: 23–25, illus.

Buell, Murray F., and Helen F. Buell.
1959. Aspen invasion of prairie. Torrey Bot. Club Bull. 86: 264–265.

Buijtenen, J. P., van, D. W. Einspahr, and Philip N. Joranson.
1959. Natural variation in *Populus tremuloides* Michx. Tappi 42: 819–823.

Buijtenen, J. P., van, D. W. Einspahr, and J. R. Peckham.
1962. Natural variation in *Populus tremuloides* Michx. II. Variation in pulp and papermaking properties. Tappi 45: 58–60.

Buijtenen, J. P., van, P. N. Joranson, and D. W. Einspahr.
1958. Diploid versus triploid aspen as pulpwood sources with reference to growth, chemical, physical, and pulping differences. Tappi 41: 170–175.

Bump, Gardiner, Robert W. Darrow, Frank C. Edminster, and Walter F. Crissey.
1947. The ruffed grouse: life history, propagation, management. 915 p., illus. New York State Conserv. Dep., Albany, N.Y.

Byelich, J., J. Cook, and R. Blouch.
1972. Management for deer. *In* Aspen: symposium proceedings. USDA For. Serv. Gen. Tech. Rep. NC-1: 154 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Cayford, J. H., and R. A. Haig.
1961. Glaze damage in forest stands in southeastern Manitoba. Can. Dep. For., For. Res. Branch. Tech. Note 102: 16 p., illus.

Chase, Clarence D., Ray E. Pfeifer, and John S. Spencer, Jr.
1970. The growing timber resource of Michigan, 1966. USDA For. Serv. Resour. Bull. NC-9: 62 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Christensen, Clyde M., Ralph L. Anderson, A. C. Hodson, and Paul O. Rudolf.
1951. Enemies of aspen. USDA For. Serv., Lake States Aspen Rep. 22: 16 p. Lake States For. Exp. Stn., St. Paul, Minn.

Church, Thomas W., Jr.
1963. Survival and growth of 12-year hybrid aspen compared to native Wisconsin stock. USDA For. Serv. Res. Note LS-22: 2 p. Lake States For. Exp. Stn., St. Paul, Minn.

Cooley, John H., and W. B. Lord.
1958. A study of aspen-balsam fir cutting methods in northern Wisconsin—five-year results. J. For. 56: 731–736, illus.

Cottam, Walter P.
1954. Prevernal leafing of aspen in Utah mountains. J. Arnold Arbor. 35: 239–250, illus.

Cox, William T.
1914. The poplar of Minnesota. *In* Minn. State For. Annu. Rep. 4: 68–79.

Davidson, A. G., and W. R. Newell.
1956. Ice storm damage. *In* Can. Dep. Agric., Annu. Rep. For. Insect and Dis. Surv. 1956: p. 23.

Day, Maurice, W.
1944. The root system of the aspen. Am. Midland Nat. 32: 502–509, illus.

Day, Maurice, W., and F. C. Strong.
1959. A study of Hypoxylon canker on aspen. Mich. Agric. Exp. Stn. Q. Bull. 41: 870–877.

DeByle, Norbert Valentine.
1964. Detection of functional intraclonal aspen root connections by tracers and excavation. For. Sci. 10: 386–396, illus.

Dils, Robert E., and Maurice W. Day.
1950. Effect of defoliation upon the growth of aspen. Mich. Agric. Exp. Stn. Q. Bull. 33: 111–113, illus.

Duncan, D. P., and A. C. Hodson.
1958. Influence of the forest tent caterpillar upon the aspen forests of Minnesota. For. Sci. 4: 71–93, illus.

Edminster, F. C.
1947. The ruffed grouse—its life story, ecology, and management. 385 p., illus. New York: The Macmillan Co.

Einspahr, Dean W., and Miles K. Benson.
1964. Production and evaluation of aspen hybrids. J. For. 62: 806–809.

Ewan, Herbert G.
1960. The poplar borer in relation to aspen stocking. USDA For. Serv., Lake States For. Exp. Stn. Tech. Note 580: 2 p. Lake States For. Exp. Stn., St. Paul, Minn.

Ewing, J.
1924. Plant successions of the brush-prairie in northwestern Minnesota. J. Ecol. 12: 238–266, illus.

Farmer, Robert E., Jr.
1962a. Aspen root sucker formation and apical dominance. For. Sci. 8: 403–410.

Farmer, Robert E., Jr.
1962b. Depth and diameter of the parent roots of aspen root suckers. Univ. Mich., Mich. For. 23: 4 p., illus.

Fernald, M. L.
1950. Gray's Manual of Botany. Ed. 8: 1,632 p., illus. New York: Am. Book Co.

Findell, Virgil E., Ray E. Pfeifer, Arthur G. Horn, and Carl H. Tubbs.
1960. Michigan's forest resources. USDA For. Serv., Lake States For. Exp. Stn., Stn. Pap. 82: 46 p., illus. Lake States For. Exp. Stn., St. Paul, Minn.

Forbes, R. S., and A. G. Davidson.
1962. Examinations of windthrown poplar trees in New Brunswick. Can. Dep. For., For. Entomol. and Pathol. Branch Bimon. Prog. Rep. 18(6): 2.

Froelich, Ronald, A. C. Hodson, A. E. Schneider, and D. P. Duncan.
1955. Influence of aspen defoliation by the forest tent caterpillar in Minnesota of (sic) on the radial growth of associated balsam fir. Univ. Minn. For. Note 45: 2 p.

Frothingham, E. H.
1915. The northern hardwood forest: its composition, growth, and management. U.S. Dep. Agric., Agric. Bull. 285: 80 p., illus.

Garrett, Peter W., and Robert Zahner.
1964. Clonal variation in suckering of aspen obscures effect of various clearcutting treatments. J. For. 62: 749–750.

Gates, Frank C.
1930. Aspen association in northern lower Michigan. Bot. Gaz. 90: 233–259, illus.

Gevorkiantz, S. R.
1956. Site index curves for aspen in the Lake States. USDA For. Serv., Lake States For. Exp. Stn. Tech. Note 464: 2 p., illus. Lake States For. Exp. Stn., St. Paul, Minn.

Ghent, A. W.
1958. Mortality of overstory trembling aspen in relation to outbreaks of the forest tent caterpillar and the spruce budworm. Ecology 39: 222–232, illus.

Graham, Samuel A.
1954. Scoring tolerance of forest trees. Univ. Mich., Mich. For. 4: 2 p.
Graham, Samuel A.
1958. Results of deer exclosure experiments in the Ottawa National Forest. North Am. Wildl. Conf. Trans. 23: 478–490.
Graham, Samuel A., and Robert P. Harrison.
1954. Insect attacks and Hypoxylon infections in aspen. J. For. 52: 741–743.
Graham, Samuel A., Robert P. Harrison, Jr., and Casey E. Westell, Jr.
1963. Aspens: Phoenix trees of the Great Lakes Region. 272 p., illus. Ann Arbor: Univ. Mich. Press.
Gullion, G. W.
1967. Ruffed grouse research and the road ahead. Minn. Conserv. Volunteer 30(175): 22–30.
Gullion, G. W.
1969. Cloquet ruffed grouse studies—Job No. 1. Minn. Game Res. Q. Prog. Rep. 28(4): 176–181.
Gullion, G. W., and Franklin J. Svoboda.
1972. Aspen—the basic habitat resource for ruffed grouse. *In* Aspen: symposium proceedings. USDA For. Serv. Gen. Tech. Rep. NC-1: 154 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.
Heimburger, C. C.
1936. Report on poplar hybridization. For. Chron. 12: 285–290.
Heimburger, C. C.
1940. Report on poplar hybridization II, 1937 and 1938. For. Chron. 16: 149–160.
Heinselman, Miron L.
1954. The extent of natural conversion to other species in the Lake States aspen-birch type. J. For. 52: 737–738.
Heinselman, Miron L.
1973. Fire in the virgin forests of the Boundary Waters Canoe Area. *In* Quat. Res. 3(3): 329–382, illus.
Heinselman, Miron L., and Z. A. Zasada.
1955. A review of literature relating to quaking aspen sites. USDA For. Serv., Lake States For. Exp. Stn., Stn. Pap. 32: 61 p. Lake States For. Exp. Stn., St. Paul, Minn.
Hepting, George H.
1971. Diseases of forest and shade trees of the United States. U.S. Dep. Agric., Agric. Handb. 386: 658 p.
Hildahl, V., and W. A. Reeks.
1960. Outbreaks of the forest tent caterpillar, *Malacosoma disstria* Hbn., and their effects on stands of trembling aspen in Manitoba and Saskatchewan. Can. Entomol. 92: 199–209, illus.
Horton, K. W., and E. J. Hopkins.
1965. Influence of fire on aspen suckering. Can. Dep. For. Publ. 1095: 19 p., illus.
Hubbard, John W.
1972. Effects of thinning on growth and yield. *In* Aspen: symposium proceedings. USDA For. Serv. Gen. Tech. Rep. NC-1: 154 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.
Jarvis, J. M.
1968. Silviculture and management of natural poplar stands. *In* Growth and utilization of poplars in Canada. Can. Dep. For. and Rural Dev., Dep. Publ. 1205: 70–87.
Joranson, Philip N.
1953. An "extra heredity" approach to aspen breeding in the Lake States. *In* USDA For. Serv., Lake States For. Exp. Stn. Misc. Rep. 22: 30–33.
Kelsey, Harlan P., and William A. Dayton.
1942. Standardized plant names. Ed. 2: 675 p. Harrisburg, Pa.: J. H. McFarland Co.
Kenety, W. H.
1917. Preliminary study of white spruce in Minnesota. Minn. Agric. Exp. Stn. Bull. 168: 30 p., illus.
Kirby, C. L., W. S. Bailey, and J. G. Gilmour.
1957. The growth and yield of aspen in Saskatchewan. Sask. Dep. Nat. Resour. Tech. Bull. 3: 67 p., illus.
Kittredge, Joseph, Jr.
1938. The interrelations of habitat, growth rate, and associated vegetation in the aspen community of Minnesota and Wisconsin. Ecol. Monogr. 8: 151–246, illus.
Kittredge, Joseph, Jr., and S. R. Gevorkiantz.
1929. Forest possibilities of aspen lands in the Lake States. Minn. Agric. Exp. Stn. Tech. Bull. 60: 84 p., illus.
Krefting, Laurits W.
1951. What is the future of the Isle Royale moose herd? North Am. Wildl. Conf. Trans. 16: 461–470, illus.
Leuschner, William A.
1972. Projecting the aspen resource in the Lake States. USDA For. Serv. Res. Pap. NC-81: 32 p. North Cent. For. Exp. Stn., St. Paul, Minn.
Little, Elbert L., Jr.
1953. Check list of native and naturalized trees of the United States (including Alaska). U.S. Dep. Agric., Agric. Handb. 41: 472 p.
Little, Elbert L., Jr., K. A. Brinkman, and A. L. McComb.
1957. Two natural Iowa hybrid poplars. For. Sci. 3: 253–262.
Maini, J. S.
1960. Invasion of grasslands by *Populus tremuloides* in the northern great plains. Ph.D. thesis, Univ. Sask., Can. 231 p.
Maini, J. S.
1967. Variation in the vegetative propagation of *Populus* in natural populations. Bull. Ecol. Soc. Am. 48: 75–76.
Maini, J. S.
1972. Silvics and ecology in Canada. *In* Aspen: symposium proceedings. USDA For. Serv. Gen. Tech. Rep. NC-1: 154 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.
Maini, J. S., and K. W. Horton.
1966. Vegetative propagation of *Populus* spp. I. Influence of temperature on formation and initial growth of aspen suckers. Can. J. Bot. 44: 1183–1189.
Marie-Victorin, Frère.
1930. Les variations Laurentiennes du *Populus tremuloides* et du *P. grandidentata*. Montreal Univ. Bot. Lab. Contrib. 16: 16 p., illus.
Marty, Robert.
1972. Economic impact of Hypoxylon canker on the Lake States aspen resource. *In* Aspen: symposium proceedings. USDA For. Serv. Gen. Tech. Rep. NC-1: 154 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.
McCaffery, Keith R., and William A. Creed.
1969. Significance of forest openings to deer in northern Wisconsin. Wis. Dep. Nat. Resour. Tech. Bull. 44: 104 p.
Morawski, Z. J. R., J. T. Basham, and K. B. Turner.
1958. A survey of a pathological condition in the forests of Ontario. Ont. Dep. Lands and For. Rep. 25: 96 p., illus.
Morbeck, George C.
1922. A Minnesota forest problem—to keep pine lands productive. J. For. 20: 533–537.

Office of Iron Range Resources and Rehabilitation and Lake States Forest Experiment Station.
1964. Timber resources of Minnesota-Lake Superior Unit, 1962: 42 p., illus. St. Paul, Minn.
Pauley, Scott S.
1956. Natural hybridization of the aspens. Univ. Minn. For. Note 47: 2 p., illus.
Pauley, Scott S., A. G. Johnson, and F. S. Santamour, Jr.
1963. Results of aspen screening tests III. F_1 hybrid progenies of quaking × European aspen. Univ. Minn. For. Note 138: 2 p.
Perala, Donald A.
1971. Aspen successfully regenerated after killing residual vegetation with herbicides. USDA For. Serv. Res. Note NC-106: 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.
Peterson, L. O. T.
1948. Some aspects of poplar borer, *Saperda calcarata* Say (Cerambycidae), infestations under parkbelt conditions. Ont. Entomol. Soc. Rep. 1947: 56–61.
Peto, F. H.
1938. Cytology of poplar species and natural hybrids. Can. J. Res. (Sec. C) 16: 445–455, illus.
Pike, R. T.
1953. Thinning aspen, Duck Mountain Forest Reserve, Manitoba. Can. Dep. Resour. and Dev., For. Branch, Silvic. Leafl. 89: 3 p.
Plonski, W. L.
1956. Normal yield tables for black spruce, jack pine, aspen and white birch in northern Ontario. Ont. Dep. Lands and For., Div. Timber Manage., Rep. 24: 40 p., illus.
Pollard, D. F. W.
1972. Estimating woody dry matter loss resulting from defoliation. For. Sci. 18: 135–138.
Povah, Alfred.
1924. Hypoxylon poplar canker. Phytopathology 14: 140-145, illus.
Prentice, R. M.
1955. The life history and some aspects of the ecology of the large aspen tortrix, *Choristoneura conflictana* (Wlkr.) (n. comb.) (*Lepidoptera: Tortricidae*). Can. Entomol. 87: 461–473, illus.
Quaite, J.
1953. Poisoning with "ammate" to eliminate aspen. Can. Dep. North. Aff. and Natl. Resour., For. Branch., Silvic. Leafl. 94: 2 p.
Riley, C. G.
1952. Studies in forest pathology. IX. *Fomes ignarius* decay of poplar. Can. J. Bot. 30: 710–734, illus.
Riley, C. G.
1953. Hail damage in forest stands. For. Chron. 29: 139–143, illus.
Roe, Eugene I.
1935. Forest soils—the basis of forest management. USDA For. Serv., Lake States For. Exp. Stn., 9 p.
Rose, A. H.
1958. The effect of defoliation on foliage production and radial growth of quaking aspen. For. Sci. 4: 335–342, illus.
Roth, Filibert.
1898. Forestry conditions and interests of Wisconsin. U.S. Dep. Agric., For. Div. Bull. 16: 76 p., illus.
Rutske, L. H.
1969. A Minnesota guide to forest game habitat improvement. Minn. Dep. Conserv. Tech. Bull. 10: 68 p. St. Paul, Minn.
Sandberg, Dixon, and Arthur E. Schneider.
1953. The regeneration of aspen by suckering. Univ. Minn. For. Note 24: 2 p.
Schantz-Hansen, T.
1945. Harvesting young aspen in the Cloquet Forest. J. For. 43: 506–507.
Schlaegel, Bryce E.
1971. Growth and yield of quaking aspen in north-central Minnesota. USDA For. Serv. Res. Pap. NC-58: 11 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.
Schlaegel, Bryce E., and Stanley B. Ringold.
1971. Thinning pole-sized aspen has no effect on number of veneer trees or total yield. USDA For. Serv. Res. Note NC-121: 11 p. North Cent. For. Exp. Stn., St. Paul, Minn.
Schmitz, Henry, and Lyle W. R. Jackson.
1927. Heart rot of aspen—with special reference to forest management in Minnesota. Minn. Agric. Exp. Stn. Tech. Bull. 50: 43 p., illus.
Shirley, Hardy L.
1941. Restoring conifers to aspen lands in the Lake States. U.S. Dep. Agric. Tech. Bull. 763: 36 p., illus.
Sippell, W. L.
1962. Outbreaks of the forest tent caterpillar, *Malacosoma disstria* Hbn., a periodic defoliator of broad-leaved trees in Ontario. Can. Entomol. 94: 408–416, illus.
Sisam, J. W. B.
1938. Site as a factor in silviculture with special reference to the use of plant indicators. Can. Dep. Mines and Resour., Lands, Parks, and For. Branch, Dom. For. Serv. Silvic. Res. Note 54: 88 p., illus.
Sorensen, Ronald W.
1968. Size of aspen crop trees little affected by initial sucker density. USDA For. Serv. Res. Note NC-51: 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.
Spencer, J. S., Jr., and H. W. Thorne.
1972. Wisconsin's 1968 timber resource—a perspective. USDA For. Serv. Resour. Bull. NC-15: 80 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.
Stearns, Forest W.
1949. Ninety years change in a northern hardwood forest in Wisconsin. Ecology 30: 350–358, illus.
Steneker, G. A.
1964. Ten-year results of thinning 14-, 19-, and 23-year-old aspen to different spacings. Can. Dep. For., For. Res. Branch Publ. 1038: 22 p., illus.
Steneker, G. A.
1972. Size and suckering of trembling aspen (*Populus tremuloides*) clones in Manitoba. Ph.D. thesis, Univ. Mich., 162 p.
Steneker, G. A., and J. M. Jaruis.
1966. Thinning in trembling aspen stands—Manitoba and Saskatchewan. Can. Dep. For., For. Res. Branch Publ. 1140: 28 p.
Stoeckeler, Joseph H.
1960. Soil factors affecting the growth of quaking aspen forests in the Lake States. Minn. Agric. Exp. Stn. Tech. Bull. 233: 48 p., illus.
Stoeckeler, Joseph H.
1961. Organic layers in Minnesota aspen stands and their role in soil improvement. For. Sci. 7: 66–71, illus.
Stoeckeler, Joseph H., and Carl Arbogast, Jr.
1955. Forest management lessons from a 1949 windstorm in northern Wisconsin and upper Michigan. USDA For. Serv., Lake States For. Exp. Stn., Stn. Pap. 34: 11 p. Lake States For. Exp. Stn., St. Paul, Minn.

Stoeckeler, Joseph H., and John W. Macon.
1956. Regeneration of aspen cutover areas in northern Wisconsin. J. For. 54: 13–16, illus.

Stone, Robert N.
1966. A third look at Minnesota's timber. USDA For. Serv. Resour. Bull. NC-1: 64 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Stone, Robert N., and Harry W. Thorne.
1961. Wisconsin's forest resources. USDA For. Serv., Lake States For. Exp. Stn., Stn. Pap. 90: 52 p., illus. Lake States For. Exp. Stn., St. Paul, Minn.

Strothmann, R. O.
1960. Evaluating the growth potential of aspen lands in northern Minnesota. USDA For. Serv., Lake States For. Exp. Stn., Stn. Pap. 86: 20 p., illus. Lake States For. Exp. Stn., St. Paul, Minn.

Strothmann, R. O., and Miron L. Heinselman.
1957. Five-year results in an aspen sucker density study. USDA For. Serv., Lake States For. Exp. Stn. Tech. Note 490: 2 p. Lake States For. Exp. Stn., St. Paul, Minn.

Tew, Ronald K.
1970. Root carbohydrate reserves in vegetative reproduction of aspen. For. Sci. 16: 318–320.

Thomas, J. B.
1956. Hail damage in Lake Nipigon area. Can. Dep. Agric., For. Biol. Div. Bimon. Rep. 12(3): 2.

Truax, T. R.
1915. Reproduction studies in the Minnesota National Forest. Ames For. 5: 80–86, illus.

USDA Forest Service.
1974. Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p., illus.

Vaartaja, O.
1960. Ecotypic variation of photoperiodic response in trees especially in two *Populus* species. For. Sci. 6: 200–206, illus.

Verry, Elon S.
1972. Effect of an aspen clearcutting on water yield and quality in northern Minnesota. *In* Am. Water Resourc. Assoc. Natl. Symp. Proc., Watersheds in Transition, Colo. State Univ., June 19–22, 1972: 276–284, illus.

Voigt, G. K., M. L. Heinselman, and Z. A. Zasada.
1957. The effect of soil characteristics on the growth of quaking aspen in northern Minnesota. Soil Sci. Soc. Am. Proc. 21: 649–652, illus.

Weitzman, Sidney, and Roger R. Bay.
1959. Snow behavior in forests of northern Minnesota and its management implications. USDA For. Serv., Lake States For. Exp. Stn., Stn. Pap. 69: 18 p., illus. Lake States For. Exp. Stn., St. Paul, Minn.

Weitzman, Sidney, and Roger R. Bay.
1963. Forest soil freezing and the influence of management practices, northern Minnesota. USDA For. Serv. Res. Pap. LS-2: 8 p., illus. Lake States For. Exp. Stn., St. Paul, Minn.

Westell, Casey E., Jr.
1954. Available browse following aspen logging in lower Michigan. J. Wildl. Manage. 18: 266–271, illus.

Westell, Casey E., Jr.
1956. Ecological relationships between deer and forests in lower Michigan. Soc. Am. For. Proc. 1955: 130–132.

Westell, Casey E., Jr.
1960. The ecology of deer and aspen in lower Michigan. Ph.D. thesis, Univ. Mich., Ann Arbor, Mich.

Wilde, S. A., and D. T. Pronin.
1950. Growth of trembling aspen in relation to ground water and soil organic matter. Soil Sci. Soc. Am. Proc. 14: 345–347, illus.

Wilde, S. A., and E. L. Zicker.
1948. Influence of the ground water table upon the distribution and growth of aspen and jack pine in central Wisconsin. Wis. Conserv. Dep. Tech. Note 30: 12 p., illus.

Worley, D. P., W. C. Bramble, and W. R. Byrnes.
1954. Effect of seasonal basal sprays on root suckering of aspen. Northeast. Weed Control Conf. Proc. 8: 447–452.

Zahner, Robert, and Ned A. Crawford.
1965. The clonal concept in aspen site relations. *In* Forest soil relationships of North America: 229–243. Oreg. State Univ., Corvallis, Oreg.

Zasada, Zigmond A.
1948. Aspen lumber grades and characteristics. USDA For. Serv., Lake States Aspen Rep. 6: 9 p. Lake States For. Exp. Stn., St. Paul, Minn.

Zasada, Zigmond A.
1972. Mechanized logging can aid management. *In* Aspen: symposium proceedings. USDA For. Serv. Gen. Tech. Rep. NC-1: 154 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Zasada, Zigmond A., and J. C. Tappeiner.
1969. Full-tree harvesting system aids forest management. Minn. For. Res. Note 205: 4 p.

Zehngraff, Paul J.
1946. Season of cutting affects aspen sprouting. USDA For. Serv., Lake States For. Exp. Stn. Tech. Note 250: 1 p. Lake States For. Exp. Stn., St. Paul, Minn.

Zehngraff, Paul J.
1947. Possibilities of managing aspen. USDA For. Serv., Lake States Aspen Rep. 21: 23 p. Lake States For. Exp. Stn., St. Paul, Minn.

Zehngraff, Paul J.
1949. Aspen as a forest crop in the Lake States. J. For. 47: 555–565, illus.

Zillgitt, W. M.
1951. Disking to increase stocking in aspen stands. USDA For. Serv., Lake States For. Exp. Stn. Tech. Note 357: 1 p. Lake States For. Exp. Stn., St. Paul, Minn.

APPENDIX I.—— COMMON AND SCIENTIFIC NAMES OF PLANT SPECIES MENTIONED[12]

Trees

Ash, black	*Fraxinus nigra* Marsh.
Ash, white	*F. americana* L.
Aspen, bigtooth	*Populus grandidentata* Michx.
Aspen, European	*P. tremula* L.
Aspen, quaking	*P. tremuloides* Michx.
Basswood, American	*Tilia americana* L.
Beech, American	*Fagus grandifolia* Ehrh.
Birch, paper	*Betula papyrifera* Marsh.
Cherry, pin	*Prunus pennsylvanica* L.f.
Cottonwood, eastern	*Populus deltoides* Bartr.
Elm, American	*Ulmus americana* L.
Fir, balsam	*Abies balsamea* (L.) Mill
Hemlock, eastern	*Tsuga canadensis* (L.) Carr.
Maple, red	*Acer rubrum* L.
Maple, sugar	*A. saccharum* Marsh.
Oak, bur	*Quercus macrocarpa* Michx.
Oak, northern red	*Q. rubra* L.
Pine, eastern white	*Pinus strobus* L.
Pine, jack	*Pinus banksiana* Lamb.
Pine, red (Norway pine)	*P. resinosa* Ait.
Poplar, balsam	*Populus balsamifera* L.
Poplar, white	*P. alba* L.
Spruce, black	*Picea mariana* (Mill.) B.S.P.
Spruce, white	*P. glauca* (Moench) Voss
Tamarack	*Larix laricina* (DuRoi) K. Koch
White-cedar, northern	*Thuja occidentalis* L.
Yellow-poplar	*Liriodendron tulipifera* L.

Shrubs and Herbs

Aster, bigleaf	*Aster macrophyllus* L.
Beadlily, yellow	*Clintonia borealis* (Ait.) Raf.
Beadruby, Canada (Canada May-flower)	*Maianthemum canadense* Desf.
Bedstraw, sweetscented	*Galium triflorum* Michx.
Blackberry	*Rubus* sp. L.
Blackberry, dwarf red	*Rubus pubescens* Raf.
Bracken, eastern	*Pteridium aquilinum* (L.) Kuhn
Bush-honeysuckle, dwarf	*Diervilla lonicera* Mill.
Chokecherry, common	*Prunus virginiana* L.
Dogbane, spreading	*Apocynum androsaemifolium* L.
Dogwood, bunchberry	*Cornus canadensis* L.
Fireweed	*Epilobium angustifolium* L.
Goldenrod	*Solidago* spp. L.
Grape	*Vitis* spp. L.
Hazel, beaked	*Corylus cornuta* Marsh.
Ladyfern	*Athyrium Filix-femina* (L.) Roth
Maple, mountain	*Acer spicatum* Lam
Meadowrue, early	*Thalictrum dioicum* L.
Raspberry, red	*Rubus idaeus* var. *strigosus* (Michx.) Maxim.
Ricegrass, roughleaf	*Oryzopsis asperifolia* Michx.
Sarsaparilla, wild	*Aralia nudicaulis* L.
Sedge	*Carex richardsonii* R. Br.
Serviceberry	*Amelanchier* spp. Medic.
Strawberry	*Fragaria* spp. L.
Sweet-fern	*Comptonia peregrina* (L.) Coult.
Twistedstalk, rosy	*Streptopus roseus* Michx.

[12]Common and scientific names are based on Little (1953), Fernald (1950), and Kelsey and Dayton (1942).

APPENDIX II.— COMMON INSECTS AND DISEASES DAMAGING QUAKING ASPEN BY SIZE OF TREE AFFECTED AND SYMPTOMS[13]

Size of aspen	*Symptoms*	*Cause*
	Insects	
Suckers	Leaf curling and dwarfing	Aphids including (*Pterocomma populifoliae* (Fitch)); speckled poplar aphids *Chaitophorus populicola* (Thomas); *Aphis maculatae* Oestlund; and others
	Leaf curling and withering	Leafhoppers of genera *Idiocerus, Oncometopia, Macropsis, Oncopsis* and *Agallia*; also the lacebug, *Corythucha elegans* Drake
	Petiole swellings and galls	Poplar petiolegall and twiggall aphids, *Pemphigus* spp.
	Tip bending and dieback	Willow shoot sawfly, *Janus abbreviatus* (Say)
	Succulent stems cut off at ground line	Armyworm, *Pseudaletia unipuncta* (Haworth) and other cutworms
	Breakage of suckers about ½ inch in diameter	Borers including *Saperda* sp. and *Oberia schaumi* LeC.
	Breakage from borers weakening stems	*Aegeria tibialis* (Harr.) and *Oberia schaumi* LeC.
	Girdling of roots	*Agrilus horni* Kerr
	Diseases	
	Dieback of young shoots and leaves	*Venturia tremulae* Aderh.
	Inkspot on leaves	*Ciborinia bifrons* (Whetz.) Whetz.
	Anthracnose of leaves	*Marssonina populi* (Lib.) Magn.
	Canker on young suckers	*Cytospora chrysosperma* (Pers.) Fries
	Insects	
Saplings and small poles	Borer galleries at base	*Saperda imitans* Felt and Joutel
	Winding tunnels underneath bark of weakened trees	Bronze poplar borer, *Agrilus liragus* Barter and Brown

[13]Sources: Boyce 1961, Graham *et al.* 1963, Hepting 1971, Baker 1972.

QUAKING ASPEN

Size of aspen	*Symptoms*	*Cause*
Saplings and small poles	Winding tunnels in bark	Bark miners of the fly family, *Agromyzidae*
	Frass-filled tunnels near branch stubs	Flat-headed borers including *Dicerca tenebrica* (Kby.); *D. divaricata* (Say); *D. callosa* Casey, and *Poecilonota cyanipes* (Say)
	Roughened areas of bark	Oystershell scale, (*Lepidosaphes ulmi* (L.)); and a wooly aphid, *Prociphilus* sp.
	Diseases	
	Rough irregular tumors at or near ground line on saplings and on trunk or branches of larger trees	*Agrobacterium tumifaciens* (E. F. Smith & Town.) Conn.
	Insects	
Small poles and larger trees	Defoliation	Forest tent caterpillar, *Malacosoma disstria* Hübner; Aspen leaf beetle, *Chrysomela crotchi* Brown; other leaf beetles including *C. scripta* F.; *C. tremulae* F.; and *C. interrupta* F.
	Leaves rolled or tied with silk	Large aspen tortrix, *Choristoneura conflictana* (Walker)
	Folded leaf margins	Leaf-rolling sawflies, *Pontania* spp.
	Galleries in sound wood of living trees	Poplar borer, *Saperda calcarata* Say
	Diseases	
	Black roughened bands on aspen trunks and gall-like knots on the branches (rough bark disease)	*Diplodia tumefaciens* (Shear) Zalasky
	Cankers, usually on trunk	*Hypoxylon mammatum* (Wahl.) Mill. Nectria spp., or *Ceratocystis* spp.
	Butt and stem rots	*Armillaria mellea* Vahl ex Fr.; *Pholiota spectabilis* Fr.; White heart rot, *Fomes ignarius* (L. ex Fr.) Kickx.; *F. applanatus* (Pers. ex S. F. Gray) Gill, *Radulum cascearium* (Morg.) Lloyd

APPENDIX III.— ASPEN YIELDS BY SITE INDEX, STAND AGE, AND BASAL AREA (Schlaegel 1971)

TABLE 12.—*Total yield per acre in tens of cubic feet, excluding bark (all trees 0.6 inch d.b.h. and larger)*

Site index	Stand age	Basal area per acre							
		20	40	60	80	100	120	140	160
	Years								
65	20	35	70	105	140	176	211	246	281
	30	45	90	134	179	224	269	314	359
	40	51	101	152	202	253	304	354	405
	50	54	109	163	218	272	327	381	436
	60	57	114	172	229	286	343	401	458
70	20	38	76	113	151	189	227	265	302
	30	48	97	145	193	241	290	338	386
	40	55	109	164	218	273	327	382	436
	50	59	117	176	235	293	352	411	469
	60	62	123	185	246	308	370	431	493
75	20	40	81	121	162	202	243	283	324
	30	52	103	155	207	259	310	362	414
	40	58	117	175	234	292	350	409	467
	50	63	126	189	251	314	377	440	503
	60	66	132	198	264	330	396	462	528
80	20	43	86	130	173	216	259	303	346
	30	55	110	165	221	276	331	386	441
	40	62	125	187	249	312	374	436	499
	50	67	134	201	268	335	402	469	536
	60	70	141	211	282	352	422	493	563
85	20	46	92	138	184	230	276	321	367
	30	59	117	176	235	293	352	411	469
	40	66	132	199	265	331	397	463	530
	50	71	142	214	285	356	427	499	570
	60	75	150	224	299	374	449	524	599
90	20	49	97	146	194	243	292	340	389
	30	62	124	186	248	310	337	435	497
	40	70	140	210	281	351	421	491	561
	50	75	151	226	302	377	452	528	603
	60	79	158	238	317	396	475	554	633

TABLE 13.—*Merchantable yield per acre in tens of cubic feet, to a 3-inch top inside bark when average stand diameter is 6 inches (all trees 3.6 inches d.b.h. and larger)*

Site index	Stand age	Basal area per acre							
		20	40	60	80	100	120	140	160
	Years								
65	20	32	64	96	128	161	192	224	256
	30	41	82	122	163	204	245	286	327
	40	47	92	139	184	231	277	323	369
	50	49	99	149	199	248	298	347	398
	60	52	104	157	209	261	313	366	418
70	20	35	69	103	138	172	207	242	275
	30	44	88	132	176	220	264	308	352
	40	50	99	150	199	249	298	348	398
	50	54	107	161	214	267	321	375	428
	60	57	112	169	224	281	337	393	450
75	20	36	74	110	148	184	222	258	295
	30	47	94	141	189	236	283	330	378
	40	53	107	160	213	266	319	373	426
	50	57	115	172	229	286	344	401	459
	60	60	120	181	241	301	361	421	482
80	20	39	78	119	158	197	236	276	316
	30	50	100	150	202	252	302	352	402
	40	57	114	171	227	285	341	398	455
	50	61	122	183	244	306	367	428	489
	60	64	129	192	257	321	385	450	513
85	20	42	84	126	168	210	252	293	335
	30	54	107	161	214	267	321	375	428
	40	60	120	181	242	302	362	422	483
	50	65	130	195	260	325	389	455	520
	60	68	137	204	273	341	409	478	546
90	20	45	88	133	177	222	266	310	355
	30	57	113	170	226	283	340	397	453
	40	64	128	192	256	320	384	448	512
	50	68	138	206	275	344	412	482	550
	60	72	144	217	289	361	433	505	577

TABLE 14.—*Merchantable yield per acre in tens of cubic feet, excluding bark, to a 3-inch top inside bark when average stand diameter is 8 inches (all trees 3.6 inches d.b.h. and larger)*

Site index	Stand age	Basal area per acre							
		20	40	60	80	100	120	140	160
	Years								
65	20	34	68	102	136	170	204	238	272
	30	44	87	130	173	217	260	304	348
	40	49	98	147	196	245	294	343	392
	50	52	106	158	211	263	317	369	422
	60	55	110	166	222	277	332	388	443
70	20	37	74	109	146	183	220	257	292
	30	46	94	140	187	233	281	327	374
	40	53	106	159	211	264	317	370	422
	50	57	113	170	227	284	341	398	454
	60	60	119	179	238	298	358	417	477
75	20	39	78	117	157	196	235	274	314
	30	50	100	150	200	251	300	350	401
	40	56	113	169	227	283	339	396	452
	50	61	122	183	243	304	365	426	487
	60	64	128	192	256	319	383	447	511
80	20	42	83	126	167	209	251	293	335
	30	53	106	160	214	267	320	374	427
	40	60	121	181	241	302	362	422	483
	50	65	130	195	259	324	389	454	519
	60	68	136	204	273	341	408	477	545
85	20	45	89	134	178	223	267	311	355
	30	57	113	170	227	284	341	398	454
	40	64	128	193	257	320	384	448	513
	50	69	137	207	276	345	413	483	552
	60	73	145	217	289	362	435	507	580
90	20	47	94	141	188	235	283	329	377
	30	60	120	180	240	300	361	421	481
	40	68	136	203	272	340	408	475	543
	50	73	146	219	292	365	438	511	584
	60	76	153	230	307	383	460	536	613

TABLE 15.—*Merchantable yield in tens of cubic feet, excluding bark, to a 3-inch top inside bark when average stand diameter is 10+ inches (all trees 3.6 inches d.b.h. and larger)*

Site index	Stand age	Basal area per acre							
		20	40	60	80	100	120	140	160
	Years								
65	20	34	69	103	137	173	207	242	276
	30	44	88	132	176	220	264	308	353
	40	50	99	149	198	248	299	348	398
	50	53	107	160	214	267	321	374	428
	60	56	112	169	225	281	337	394	450
70	20	37	75	111	148	186	223	260	297
	30	47	95	142	190	237	285	332	379
	40	54	107	161	214	268	321	375	428
	50	58	115	173	231	288	346	404	461
	60	61	121	182	242	302	363	423	484
75	20	39	80	119	159	198	239	278	318
	30	51	101	152	203	254	304	355	407
	40	57	115	172	230	287	344	402	459
	50	62	124	186	246	308	370	432	494
	60	65	130	194	259	324	389	454	518
80	20	42	84	128	170	212	254	298	340
	30	54	108	162	217	271	325	379	433
	40	61	123	184	245	306	367	428	490
	50	66	132	197	263	329	395	461	526
	60	69	138	207	277	346	414	484	553
85	20	45	90	136	181	226	271	315	360
	30	58	115	173	231	288	346	404	461
	40	65	130	195	260	325	390	455	520
	50	70	139	210	280	350	419	490	560
	60	74	147	220	294	367	441	515	588
90	20	48	95	143	191	239	287	334	382
	30	61	122	183	244	304	366	427	488
	40	69	137	206	276	345	413	482	551
	50	74	148	222	297	370	444	518	592
	60	78	155	234	311	389	466	544	622

TABLE 16.—*Merchantable yield in tens of cubic feet, excluding bark, to a 5-inch top inside bark when average stand diameter is 6 inches (all trees 5.6 inches d.b.h. and larger)*

Site index	Stand age	Basal area per acre							
		20	40	60	80	100	120	140	160
	Years								
65	20	20	39	59	78	98	118	137	157
	30	25	50	75	100	125	150	175	200
	40	28	56	85	113	141	170	198	226
	50	30	61	91	122	152	182	213	243
	60	32	64	96	128	160	191	224	256
70	20	21	42	63	84	105	127	148	169
	30	27	54	81	108	134	162	189	215
	40	31	41	92	122	152	182	213	243
	50	33	65	98	131	163	196	229	262
	60	35	69	103	137	172	206	240	275
75	20	22	45	68	90	113	136	158	181
	30	29	57	86	116	145	173	202	231
	40	32	65	98	131	163	195	228	261
	50	35	70	105	140	175	210	246	281
	60	37	74	110	147	184	221	258	295
80	20	24	48	73	97	121	145	169	193
	30	31	61	92	123	154	185	215	246
	40	35	70	104	139	174	209	243	278
	50	37	75	112	150	187	224	262	299
	60	39	79	118	157	196	235	275	314
85	20	26	51	77	103	128	154	179	205
	30	33	65	98	131	163	196	229	262
	40	37	74	111	148	185	222	258	296
	50	40	79	119	159	199	238	278	318
	60	42	84	125	167	209	251	292	334
90	20	27	54	81	108	136	163	190	217
	30	35	70	104	138	173	208	243	277
	40	39	78	117	157	196	235	274	313
	50	42	84	126	169	210	252	295	336
	60	44	88	133	177	221	265	309	353

Table 17. —*Merchantable yield in tens of cubic feet, excluding bark, to a 5-inch top inside bark when average stand diameter is 8 inches (all trees 5.6 inches d.b.h. and larger)*

Site index	Stand age	Basal area per acre							
		20	40	60	80	100	120	140	160
	Years								
65	20	30	59	89	118	148	178	207	237
	30	38	76	113	151	189	227	265	303
	40	43	85	128	170	213	256	298	341
	50	46	92	137	184	229	276	321	368
	60	48	96	145	193	241	289	338	386
70	20	32	64	95	127	159	191	223	255
	30	40	82	122	163	203	244	285	325
	40	46	92	138	184	230	276	322	368
	50	50	99	148	198	247	297	346	395
	60	52	104	156	207	260	312	363	416
75	20	34	68	102	137	170	205	239	273
	30	44	87	131	175	218	261	305	349
	40	49	99	148	197	246	295	345	394
	50	53	106	159	212	265	318	371	424
	60	56	111	167	223	278	334	389	445
80	20	36	72	110	146	182	218	255	292
	30	46	93	139	186	233	279	325	372
	40	52	105	158	210	263	315	368	421
	50	56	113	169	226	282	339	395	452
	60	59	119	178	238	297	356	416	475
85	20	39	78	116	155	194	233	271	309
	30	50	99	148	198	247	297	346	395
	40	56	111	168	223	279	335	390	447
	50	60	120	180	240	300	360	421	481
	60	63	126	189	252	315	379	442	505
90	20	41	82	123	164	205	246	287	328
	30	52	105	157	209	261	314	367	419
	40	59	118	177	237	296	355	414	473
	50	63	127	191	255	318	381	445	508
	60	67	133	201	267	334	400	467	534

TABLE 18.—*Merchantable yield in tens of cubic feet, excluding bark, to a 5-inch top inside bark when average stand diameter is 10+ inches (all trees 5.6 inches d.b.h. and larger)*

Site index	Stand age	Basal area per acre							
		20	40	60	80	100	120	140	160
	Years								
65	20	33	66	98	131	165	197	230	263
	30	42	84	125	168	210	252	294	336
	40	48	95	142	189	237	285	331	379
	50	51	102	153	204	255	306	357	408
	60	53	107	161	214	268	321	375	429
70	20	36	71	106	141	177	212	248	283
	30	45	91	136	181	226	271	316	361
	40	51	102	154	204	256	306	358	408
	50	55	110	165	220	274	329	385	439
	60	58	115	173	230	288	346	403	461
75	20	37	76	113	152	189	227	265	303
	30	49	96	145	194	242	290	339	388
	40	54	110	164	219	273	328	383	437
	50	59	118	177	235	294	353	412	471
	60	62	124	185	247	309	371	432	494
80	20	40	80	122	162	202	242	284	324
	30	51	103	154	207	258	310	361	413
	40	58	117	175	233	292	350	408	467
	50	63	125	188	251	314	376	439	502
	60	66	132	197	264	329	395	461	527
85	20	43	86	129	172	215	258	300	344
	30	55	110	165	220	274	329	385	439
	40	62	124	186	248	310	372	433	496
	50	62	133	200	267	333	400	467	534
	60	70	140	210	280	350	420	490	561
90	20	46	91	137	182	227	273	318	364
	30	58	116	174	232	290	349	407	465
	40	66	131	197	263	329	394	460	525
	50	70	141	212	283	353	423	494	564
	60	74	148	223	297	371	445	519	592

TABLE 19.—*Average aspen yields in cords per acre to 3-inch and 5-inch top diameters inside bark*

Site index	Age	Height	Basal area per acre 40[1]		60[1]		80[1]		100[1]		120[1]		140[1]	
90	20	58	9.2	0	12.4	0	12.8	0	10.8	0				
	30	74	14.6	10.0	21.2	12.2	27.0	10.4	31.0	3.9	32.6	0	28.6	0
	40	83	17.2	15.4	25.5	21.8	33.8	26.3	41.3	27.5	47.4	24.5	52.2	14.9
	50	90	18.7	18.0	28.0	26.3	37.5	34.4	46.3	40.6	54.4	43.5	62.2	42.8
	60	94	19.6	19.4	29.5	28.9	39.3	38.1	49.1	46.6	58.9	53.5	68.0	58.9
80	20	52	8.2	0	11.0	0	11.4	0	9.6	0				
	30	66	12.9	8.9	18.8	10.9	24.1	9.2	27.6	3.5	28.9	0	25.4	0
	40	74	15.3	13.8	22.7	19.4	29.9	23.3	36.7	24.5	42.1	21.8	46.4	13.2
	50	80	16.6	15.9	24.9	23.4	33.2	30.5	41.1	36.0	48.3	38.7	55.2	38.0
	60	84	17.5	17.3	26.2	25.6	35.0	33.9	43.7	41.4	52.3	47.5	60.5	52.4
70	20	46	7.2	0	9.6	0	9.9	0	8.4	0				
	30	57	11.4	7.8	16.5	9.5	21.0	8.1	24.1	3.0	25.3	0	22.4	0
	40	65	13.4	12.0	19.9	17.0	26.2	20.4	32.1	21.4	36.8	19.0	40.6	11.6
	50	70	14.5	13.9	21.8	20.5	29.1	26.8	36.0	31.5	42.3	33.9	48.4	33.3
	60	73	15.2	15.1	22.9	22.5	30.5	29.6	38.2	36.2	45.9	41.7	52.9	45.8

[1]Left column shows merchantable cords to 3-inch top diameter; right column, to 5-inch top diameter.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1976 O—579-943